

IMMUNE REACTIVITY TO HER-2/*NEU* PROTEIN  
FOR DIAGNOSIS AND TREATMENT OF MALIGNANCIES  
IN WHICH THE HER-2/*NEU* ONCOGENE IS ASSOCIATED

CROSS REFERENCES TO RELATED APPLICATIONS

5           This application is a continuation of U.S. Patent Application  
No. 09/354,533, filed July 15, 1999 and allowed; which application is a  
continuation of U.S. Patent Application No. 08/466,680, filed June 6, 1995, which  
issued as U.S. Patent No. 6,075,122; which application is a continuation of U.S.  
Patent Application No. 08/414,417, filed March 31, 1995 which issued as U.S.  
10 Patent No. 5,801,005; which application is a continuation-in-part of U.S. Patent  
Application No. 08/106,112, filed August 12, 1993 and abandoned; which  
application is a continuation-in-part of U.S. Patent Application No. 08/033,644,  
filed March 17, 1993 and abandoned; which applications are incorporated by  
reference herein in their entirety.

15 BACKGROUND OF THE INVENTION

Field of the Invention

          The present invention is generally directed toward the detection,  
monitoring, and treatment of malignancies, in which the HER-2/*neu* oncogene is  
associated, through the use of a cancer patient's own immune reactivity to the  
20 HER-2/*neu* protein expressed by the HER-2/*neu* gene.

Description of the Related Art

          Despite enormous investments of financial and human resources,  
cancer remains one of the major causes of death. For example, cancer is the  
leading cause of death in women between the ages of 35 and 74. Breast cancer  
25 is the most common malignancy in women and the incidence for developing breast

cancer is on the rise. One in nine women will be diagnosed with the disease. Standard approaches to cure breast cancer have centered around a combination of surgery, radiation and chemotherapy. These approaches have resulted in some dramatic successes in certain malignancies. However, breast cancer is most often incurable, when diagnosed beyond a certain stage. Alternative approaches to early diagnosis and therapy are necessary.

A common characteristic of malignancies is uncontrolled cell growth. Cancer cells appear to have undergone a process of transformation from the normal phenotype to a malignant phenotype capable of autonomous growth. Amplification and overexpression of somatic cell genes is considered to be a common primary event that results in the transformation of normal cells to malignant cells. The malignant phenotypic characteristics encoded by the oncogenic genes are passed on during cell division to the progeny of the transformed cells.

Ongoing research involving oncogenes has identified at least forty oncogenes operative in malignant cells and responsible for, or associated with, transformation. Oncogenes have been classified into different groups based on the putative function or location of their gene products (such as the protein expressed by the oncogene).

Oncogenes are believed to be essential for certain aspects of normal cellular physiology. In this regard, the *HER-2/neu* oncogene is a member of the tyrosine protein kinase family of oncogenes and shares a high degree of homology with the epidermal growth factor receptor. *HER-2/neu* presumably plays a role in cell growth and/or differentiation. *HER-2/neu* appears to induce malignancies through quantitative mechanisms that result from increased or deregulated expression of an essentially normal gene product.

*HER-2/neu* (p185) is the protein product of the *HER-2/neu* oncogene. The *HER-2/neu* gene is amplified and the *HER-2/neu* protein is overexpressed in a variety of cancers including breast, ovarian, colon, lung and

prostate cancer. HER-2/*neu* is related to malignant transformation. It is found in 50%-60% of ductal *in situ* carcinoma and 20%-40% of all breast cancers, as well as a substantial fraction of adenocarcinomas arising in the ovaries, prostate, colon and lung. HER-2/*neu* is intimately associated not only with the malignant phenotype, but also with the aggressiveness of the malignancy, being found in one-fourth of all invasive breast cancers. HER-2/*neu* overexpression is correlated with a poor prognosis in both breast and ovarian cancer. HER-2/*neu* is a transmembrane protein with a relative molecular mass of 185 kd that is approximately 1255 amino acids (aa) in length. It has an extracellular binding domain (ECD) of approximately 645 aa, with 40% homology to epidermal growth factor receptor (EGFR), a highly hydrophobic transmembrane anchor domain (TMD), and a carboxyterminal cytoplasmic domain (CD) of approximately 580 aa with 80% homology to EGFR.

An approach to developing a diagnostic assay for malignancies, in which the HER-2/*neu* oncogene is associated, has been to attempt to quantify the protein expression product of the HER-2/*neu* oncogene in tissue or body fluids. However, there have been problems in the development of diagnostic assays based on direct detection of HER-2/*neu* protein.

Due to the difficulties in the current approaches to diagnosis and therapy of cancers in which the HER-2/*neu* oncogene is associated, there is a need in the art for improved methods and compositions. The present invention fills this need, and further provides other related advantages.

#### SUMMARY OF THE INVENTION

Briefly stated, the present invention provides a variety of methods for the detection of a malignancy in a warm-blooded animal, wherein a HER-2/*neu* oncogene is associated with the malignancy. The methods may be used on a one time basis when a malignancy is suspected or on a periodic basis, e.g., to monitor an individual with an elevated risk of acquiring or reacquiring a malignancy. In one

embodiment, the method comprises the steps of: (a) isolating CD4<sup>+</sup> T cells from a warm-blooded animal; (b) incubating the T cells with HER-2/*neu* protein; and (c) detecting the presence or absence of specific activation of the T cells, thereby determining the presence or absence of the malignancy. In another embodiment, the method comprises the steps of: (a) isolating CD8<sup>+</sup> T cells from a warm-blooded animal; (b) incubating the T cells with HER-2/*neu* protein; and (c) detecting the presence or absence of specific activation of the T cells, thereby determining the presence or absence of the malignancy. In another embodiment, the method comprises the steps of: (a) contacting a body fluid, suspected of containing antibodies specific for HER-2/*neu* protein, with HER-2/*neu* protein; (b) incubating the body fluid under conditions and for a time sufficient to allow immunocomplexes to form; and (c) detecting the presence or absence of immunocomplexes formed between the HER-2/*neu* protein and antibodies in the body fluid specific for the HER-2/*neu* protein, thereby determining the presence or absence of the malignancy.

In another aspect, the present invention provides methods for monitoring the effectiveness of cancer therapy in a warm-blooded animal with a malignancy, wherein a HER-2/*neu* oncogene is associated with the malignancy. Uses of such methods include the early detection of relapse. In one embodiment, the method comprises the steps of: (a) contacting a first body fluid sample, taken from the warm-blooded animal prior to initiation of therapy, with HER-2/*neu* protein; (b) incubating the body fluid under conditions and for a time sufficient to allow immunocomplexes to form; (c) detecting immunocomplexes formed between the HER-2/*neu* protein and antibodies in the body fluid specific for the HER-2/*neu* protein; (d) repeating steps (a), (b), and (c) on a second body fluid sample taken from the animal subsequent to the initiation of therapy; and (e) comparing the number of immunocomplexes detected in the first and second body fluid samples, thereby monitoring the effectiveness of the therapy in the animal.

The present invention is also directed toward methods for treating a malignancy in a warm-blooded animal, wherein a HER-2/*neu* oncogene is associated with the malignancy. In one embodiment, the method comprises the steps of: (a) isolating CD4<sup>+</sup> T cells from a warm-blooded animal; (b) incubating the T cells in the presence of HER-2/*neu* protein, such that the T cells proliferate; and (c) administering to the warm-blooded animal an effective amount of the proliferated T cells. In another embodiment, the method comprises the steps of: (a) isolating CD8<sup>+</sup> T cells from a warm-blooded animal; (b) incubating the T cells in the presence of HER-2/*neu* protein, such that the T cells proliferate; and (c) administering to the warm-blooded animal an effective amount of the proliferated T cells. In another embodiment, the method comprises the steps of: (a) isolating CD4<sup>+</sup> T cells from a warm-blooded animal; (b) incubating the T cells in the presence of HER-2/*neu* protein, such that the T cells proliferate; (c) cloning one or more cells that proliferated in the presence of HER-2/*neu* protein; and (d) administering to the warm-blooded animal an effective amount of the cloned T cells. In another embodiment, the method comprises the steps of: (a) isolating CD8<sup>+</sup> T cells from a warm-blooded animal; (b) incubating the T cells in the presence of HER-2/*neu* protein, such that the T cells proliferate; (c) cloning one or more cells that proliferated in the presence of HER-2/*neu* protein; and (d) administering to the warm-blooded animal an effective amount of the cloned T cells. In yet another embodiment, the method comprises immunizing the animal with a HER-2/*neu* peptide recognized by T cells, the peptide not being the extracellular domain of the protein expression product of a HER-2/*neu* oncogene.

Within a related aspect, the present invention provides anti-cancer therapeutic compositions comprising T cells proliferated in the presence of HER-2/*neu* protein, in combination with a pharmaceutically acceptable carrier or diluent. In addition, a variety of peptides designated for CD8<sup>+</sup> T cell responses are provided which include peptides consisting essentially of:

His-Leu-Tyr-Gln-Gly-Cys-Gln-Val-Val (Seq. ID No. 1);  
 Pro-Leu-Gln-Pro-Glu-Gln-Leu-Gln-Val (Seq. ID No. 2);  
 Pro-Leu-Thr-Ser-Ile-Ile-Ser-Ala-Val (Seq. ID No. 3);  
 Ile-Leu-Leu-Val-Val-Val-Leu-Gly-Val (Seq. ID No. 4);  
 5 Leu-Leu-Val-Val-Val-Leu-Gly-Val-Val (Seq. ID No. 5);  
 Arg-Leu-Leu-Gln-Glu-Thr-Glu-Leu-Val (Seq. ID No. 6);  
 Cys-Leu-Thr-Ser-Thr-Val-Gln-Leu-Val (Seq. ID No. 7);  
 Asp-Leu-Ala-Ala-Arg-Asn-Val-Leu-Val (Seq. ID No. 8);  
 Val-Leu-Val-Lys-Ser-Pro-Asn-His-Val (Seq. ID No. 9);  
 10 Thr-Leu-Ser-Pro-Gly-Lys-Asn-Gly-Val (Seq. ID No. 10);  
 Val-Leu-Gly-Val-Val-Phe-Gly-Ile-Leu (Seq. ID No. 11);  
 Leu-Ile-Lys-Arg-Arg-Gln-Gln-Lys-Ile (Seq. ID No. 12);  
 Lys-Ile-Pro-Val-Ala-Ile-Lys-Val-Leu (Seq. ID No. 13);  
 Ile-Leu-Asp-Glu-Ala-Tyr-Val-Met-Ala (Seq. ID No. 14);  
 15 Gln-Leu-Met-Pro-Tyr-Gly-Cys-Leu-Leu (Seq. ID No. 15);  
 Gln-Ile-Ala-Lys-Gly-Met-Ser-Tyr-Leu (Seq. ID No. 16);  
 Leu-Leu-Asn-Trp-Cys-Met-Gln-Ile-Ala (Seq. ID No. 17);  
 Arg-Leu-Val-His-Arg-Asp-Leu-Ala-Ala (Seq. ID No. 18);  
 Asp-Ile-Asp-Glu-Thr-Glu-Tyr-His-Ala (Seq. ID No. 19);  
 20 Asp-Leu-Leu-Glu-Lys-Gly-Glu-Arg-Leu (Seq. ID No. 20);  
 Thr-Ile-Asp-Val-Tyr-Met-Leu-Met-Val (Seq. ID No. 21);  
 Met-Ile-Met-Val-Lys-Cys-Trp-Met-Ile (Seq. ID No. 22);  
 Asp-Leu-Val-Asp-Ala-Glu-Glu-Tyr-Leu (Seq. ID No. 23);  
 Gly-Leu-Glu-Pro-Ser-Glu-Glu-Glu-Ala (Seq. ID No. 24); or  
 25 Tyr-Leu-Thr-Pro-Gln-Gly-Gly-Ala-Ala (Seq. ID No. 25).

Similarly, a variety of peptides designated for CD4+ T cell responses  
 are provided which include peptides consisting essentially of:

30 His-Leu-Asp-Met-Leu-Arg-His-Leu-Tyr-Gln-Gly-Cys-Gln-Val-Val (Seq. ID No. 30);  
 Pro-Leu-Gln-Arg-Leu-Arg-Ile-Val-Arg-Gly-Thr-Gln-Leu-Phe-Glu (Seq. ID No. 31);  
 Leu-Arg-Ser-Leu-Thr-Glu-Ile-Leu-Lys-Gly-Gly-Val-Leu-Ile-Gln (Seq. ID No. 32);  
 Val-Thr-Tyr-Asn-Thr-Asp-Thr-Phe-Glu-Ser-Met-Pro-Asn-Pro-Glu (Seq. ID No. 33);  
 His-Leu-Arg-Glu-Val-Arg-Ala-Val-Thr-Ser-Ala-Asn-Ile-Gln-Glu (Seq. ID No. 34);

Val-Arg-Ala-Val-Thr-Ser-Ala-Asn-Ile-Gln-Glu-Phe-Ala-Gly-Cys (Seq. ID No. 35);  
 Asn-Ile-Gln-Glu-Phe-Ala-Gly-Cys-Lys-Lys-Ile-Phe-Gly-Ser-Leu (Seq. ID No. 36);  
 Gln-Val-Phe-Glu-Thr-Leu-Glu-Glu-Ile-Thr-Gly-Tyr-Leu-Tyr-Ile (Seq. ID No. 37);  
 Gln-Glu-Cys-Val-Glu-Glu-Cys-Arg-Val-Leu-Gln-Gly-Leu-Pro-Arg (Seq. ID No. 38);  
 5 Val-Val-Val-Leu-Gly-Val-Val-Phe-Gly-Ile-Leu-Ile-Lys-Arg-Arg (Seq. ID No. 39);  
 Lys-Tyr-Thr-Met-Arg-Arg-Leu-Leu-Gln-Glu-Thr-Glu-Leu-Val-Glu (Seq. ID No. 40);  
 Gly-Ala-Met-Pro-Asn-Gln-Ala-Gln-Met-Arg-Ile-Leu-Lys-Glu-Thr (Seq. ID No. 41);  
 Val-Lys-Val-Leu-Gly-Ser-Gly-Ala-Phe-Gly-Thr-Val-Tyr-Lys-Gly (Seq. ID No. 42);  
 Ser-Pro-Lys-Ala-Asn-Lys-Glu-Ile-Leu-Asp-Glu-Ala-Tyr-Val-Met (Seq. ID No. 43);  
 10 Gly-Val-Gly-Ser-Pro-Tyr-Val-Ser-Arg-Leu-Leu-Gly-Ile-Cys-Leu (Seq. ID No. 44);  
 Ser-Arg-Leu-Leu-Gly-Ile-Cys-Leu-Thr-Ser-Thr-Val-Gln-Leu-Val (Seq. ID No. 45);  
 Gly-Ser-Gln-Asp-Leu-Leu-Asn-Trp-Cys-Met-Gln-Ile-Ala-Lys-Gly (Seq. ID No. 46);  
 Val-Lys-Ile-Thr-Asp-Phe-Gly-Leu-Ala-Arg-Leu-Leu-Asp-Ile-Asp (Seq. ID No. 47);  
 Thr-Val-Trp-Glu-Leu-Met-Thr-Phe-Gly-Ala-Lys-Pro-Tyr-Asp-Gly (Seq. ID No. 48);  
 15 Pro-Ala-Arg-Glu-Ile-Pro-Asp-Leu-Leu-Glu-Lys-Gly-Glu-Arg-Leu (Seq. ID No. 49);  
 Arg-Phe-Arg-Glu-Leu-Val-Ser-Glu-Phe-Ser-Arg-Met-Ala-Arg-Asp (Seq. ID No. 50);  
 Glu-Asp-Asp-Asp-Met-Gly-Asp-Leu-Val-Asp-Ala-Glu-Glu-Tyr-Leu (Seq. ID No. 51);  
 Gly-Met-Gly-Ala-Ala-Lys-Gly-Leu-Gln-Ser-Leu-Pro-Thr-His-Asp (Seq. ID No. 52);  
 Thr-Cys-Ser-Pro-Gln-Pro-Glu-Tyr-Val-Asn-Gln-Pro-Asp-Val-Arg (Seq. ID No. 53);  
 20 Thr-Leu-Glu-Arg-Pro-Lys-Thr-Leu-Ser-Pro-Gly-Lys-Asn-Gly-Val (Seq. ID No. 54);  
 Gly-Gly-Ala-Val-Glu-Asn-Pro-Glu-Tyr-Leu-Thr-Pro-Gln-Gly-Gly (Seq. ID No. 55);  
 Asn-Gln-Glu-Val-Thr-Ala-Glu-Asp-Gly-Thr-Gln-Arg-Cys-Glu-Lys (Seq. ID No. 56);  
 Gln-Val-Ile-Arg-Gly-Arg-Ile-Leu-His-Asn-Gly-Ala-Tyr-Ser-Leu (Seq. ID No. 57);  
 Leu-Gln-Val-Phe-Glu-Thr-Leu-Glu-Glu-Ile-Thr-Gly-Tyr-Leu-Tyr (Seq. ID No. 58);  
 25 Ala-Ser-Pro-Leu-Thr-Ser-Ile-Ile-Ser-Ala-Val-Val-Gly-Ile-Leu (Seq. ID No. 59);  
 Thr-Gln-Arg-Cys-Glu-Lys-Cys-Ser-Lys-Pro-Cys-Ala-Arg-Val-Cys-  
 Tyr-Gly-Leu (Seq. ID No. 60);  
 Arg-Leu-Arg-Ile-Val-Arg-Gly-Thr-Gln-Leu-Phe-Glu-Asp-Asn-Tyr-Ala-Leu  
 (Seq. ID No. 61);  
 30 Lys-Ile-Phe-Gly-Ser-Leu-Ala-Phe-Leu-Pro-Glu-Ser-Phe-Asp-Gly-Asp (Seq. ID No. 62);  
 Arg-Arg-Leu-Leu-Gln-Glu-Thr-Glu-Leu-Val-Glu-Pro-Leu-Thr-Pro-Ser (Seq. ID No. 63); or  
 Glu-Leu-Val-Ser-Glu-Phe-Ser-Arg-Met-Ala-Arg-Asp-Pro-Gln (Seq. ID No. 64).

Additional peptides are provided and include a peptide consisting essentially of the amino acid sequence of Figure 1 from lysine, amino acid 676, to valine, amino acid 1255.

These and other aspects of the present invention will become  
5 evident upon reference to the following detailed description and attached drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows that p185HER-2/*neu* protein (SEQ ID NO: 68) contains multiple segments with amino acid sequences appropriate for binding to  
10 class II MHC molecules. Each outlined amino acid represents the center point of an 11-mer peptide with alpha-helical periodicity and amphipathicity. Each underlined amino acid segment represents an epitope corresponding to Rothbard and Taylor motifs.

Figure 2 graphically illustrates the results of a low frequency event  
15 screening from a normal individual indicating that a CD4<sup>+</sup> T cell response can be detected against p185HER-2/*neu* and peptides derived from its amino acid sequence. The graph represents the data from one normal individual analyzed with the low frequency screening assayed described further below. Positive responses to the intact protein and two peptides were detected.

20 Figure 3 (panels A-D) graphically illustrates that CD4<sup>+</sup> T cells reactive to p185HER-2/*neu* protein and peptides can be detected in high frequency from patients with HER-2/*neu* positive breast cancer and can also be detected in some patients with tumors that test negatively for expression of p185HER-2/*neu* protein. All four breast cancer patients represented here, patient  
25 A (panel A), patient B (panel B), patient C (panel C), and patient D (panel D), were premenopausal women. Patient A had a primary tumor that tested negatively for overexpression of p185HER-2/*neu*. The other three patients had HER-2/*neu* positive tumors. A proliferation assay was performed using purified peripheral



blood mononuclear cells (PBMC) as described below, with each experimental group done in 24 well replicate. Two x 10<sup>5</sup> PBMC/well were incubated with no antigen, tetanus toxoid (5 µg/ml), p185<sup>HER-2/neu</sup> (50 µg/ml), or HER-2/*neu* derived peptides (50 µg/ml) as described further below. After 4 days, wells were  
5 pulsed with 1 µ Ci of tritiated thymidine (<sup>3</sup>H-TdR) for 6-8 hours and then counted. The data represents the mean of 24 determinations of the c.p.m. with standard error bars expressed.

Figure 4 (panels A and B) graphically illustrates that CD8<sup>+</sup> CTL specific for HER-2/*neu* peptides 48-56 and 789-797 can be generated by *in vitro*  
10 immunization. Three x 10<sup>7</sup> PBMC from a homozygous HLA-A2 normal donor were incubated with p48-56 or p789-797<sup>HER-2/neu</sup> peptides at concentrations of 10 µg/ml. The lymphocytes were tested for lytic activity after 10 *in vitro* sensitizations (IVS). Data is depicted after the tenth IVS with p48-56 (panel A) or with p789-797 (panel B). Target cells consisted of <sup>51</sup>Cr-labeled autologous EBV  
15 transformed B lymphocytes which had been incubated with p48-56 or p789-797<sup>HER-2/neu</sup> or an irrelevant peptide for 2 hours prior to use. A four hour chromium release assay (CRA) was performed. The results represent the percent specific lysis at the indicated effector:target (E:T) ratio. Target controls of <sup>51</sup>Cr-labeled K562 and Daudi cells were also included to evaluate NK and LAK activity.  
20 The execution of the CRA is as described. The results represent the percent specific lysis at the indicated effector:target (E:T) ratio.

Figure 5 pictorially illustrates that antibodies are detectable against p185<sup>HER-2/neu</sup> in the sera of a breast cancer patient. Lane 1 represents the immunoblot of p185 using a HER-2/*neu* positive breast cancer patient's sera  
25 (1:1000 dilution) as primary antibody. The blot was analyzed as described further below. Lane 2 represents the control strip from that experiment developed with c-*neu* antibody.

Figure 6 pictorially shows that antibodies in the sera of a breast cancer patient identify the same p185 band as does a known HER-2/*neu*-specific

antibody ("control antibody"). A membrane preparation from NIH3T3 cells (a murine cell line) that had been transfected with HER-2/*neu* cDNA ("NIH3T3 + H2N") was tested against control antibody (lane A) or patient sera (lane D). Similarly, a membrane preparation from untransfected cells ("NIH3T3") was tested  
5 against control antibody (lane B) or patient sera (lane C).

Figure 7 pictorially illustrates that some breast cancer patients have antibodies directed to both the extracellular and intracellular domain of the HER-2/*neu* protein. Sera of breast cancer patients is tested against the extracellular domain ("ECD protein") or the intracellular domain ("ICD protein"), in lanes A and  
10 B, respectively.

Figure 8 graphically illustrates that rats immunized with peptides derived from the intracellular domain (ICD) portion of rat *neu* protein develop antibody responses to *neu* protein. An ELISA was performed to evaluate peptide immunized animals for antibody responses to non-transforming rat *neu* protein.  
15 Each sera was analyzed at a 1:25, 1:50, 1:100, and 1:200 dilution. The OD value shown is that of the background wells subtracted from the wells coated with *neu* protein. All data shown is at a rat sera concentration of 1:25. Control sera was derived from an animal immunized with adjuvant alone. Antibody responses titrated with decreasing serum concentrations. Results were reproducible in 3  
20 separately run assays.

Figure 9 graphically illustrates that rats immunized with peptides derived from the extracellular domain (ECD) portion of rat *neu* protein develop antibody responses to *neu* protein. ELISA evaluation was performed as described in Figure 8. All data shown is at a rat sera concentration of 1:25. Control sera  
25 was derived from an animal immunized with adjuvant alone. Antibody responses titrated with decreasing serum concentrations. Results were reproducible in 3 separately run assays.

Figure 10 graphically shows that epitope analysis of ICD antibody responses demonstrates dominant B cell epitopes as well as "determinant

spreading" between domains. ELISA analysis for peptide epitopes was performed. Each animal's sera was evaluated at dilutions of 1:25, 1:50, 1:100, and 1:200 for each peptide analyzed. Antibody responses titrated with decreasing serum concentrations. All data shown is at a rat sera concentration of 1:50.

- 5 Control sera analyzed was pooled sera from 5 non-immunized animals. Results were reproducible in 3 separately run assays.

Figure 11 graphically shows that epitope analysis of ECD antibody responses demonstrates dominant B cell epitopes. ELISA analysis for peptide epitopes was performed. Each animal's sera was evaluated at dilutions of 1:25,  
10 1:50, 1:100, and 1:200 for each peptide analyzed. Antibody responses titrated with decreasing serum concentrations. All data shown is at a rat sera concentration of 1:50. Control sera analyzed was pooled sera from 5 non-immunized animals. Results were reproducible in 3 separately run assays.

Figure 12 pictorially illustrates that antibodies elicited by  
15 immunization to either ICD or ECD peptides are specific for and can immunoprecipitate both rat *neu* protein and human HER-2/*neu* protein. Panel A shows the results of an immunoprecipitation experiment with immunized rat sera and lysates of DHFRG-8. Each sera was able to immunoprecipitate rat *neu* from the cell lysates. The immunoprecipitates were resolved on a 7.5% SDS-  
20 acrylamide gel and transferred to nitrocellulose. The blots were probed with primary antibody, c-*neu*-Ab-3, at a 1:1000 dilution. Control sera of an animal immunized with the adjuvant alone showed no evidence of reactivity to rat *neu*. Panel B depicts the results of an immunoprecipitation experiment with immunized rat sera and lysates of SKBR3, a source of human *neu*. Immunoblotting was  
25 performed in an identical manner and all experimental animal sera were able to immunoprecipitate human *neu*. The control sera, again, showed no evidence of reactivity.

Figure 13 pictorially illustrates that B cell epitopes that are cross reactive between human and rat *neu* are present in both domains of the protein.

Shown here are the results of Western blot analysis of protein domain epitope mapping from representative animals in each immunized group. Animal 1.2 was immunized with the ECD group of peptides, animal 2.2 with the ICD group of peptides, and the control animal was immunized with adjuvant alone. Proteins were electrophoresed. After transfer to nitrocellulose the blots were incubated for 18 hours in rat sera at a 1:500 dilution. Antibody responses were detected with a second step goat anti-rat Ig HRP antibody at a dilution of 1:5000. Responses were detected to both human and rat *neu* as well as to both human ICD and ECD domain recombinant proteins. Antibody responses to these proteins could not be detected in the control animal which was immunized with adjuvant alone. Although data are shown here for animals 1.2, 2.2, and control, all animals in each group had the same pattern of response.

Figure 14 graphically illustrates that immunization of rats with ICD peptides elicits *neu* peptide-specific T cell responses.  $2 \times 10^5$  immunized spleen cells were incubated with 25  $\mu\text{g}/\text{ml}$  of the various peptides. The "Mix" group consisted of 25  $\mu\text{g}/\text{ml}$  each of the immunizing peptides. A proliferation assay was performed. Each experimental group was done in 6 well replicates. The data is expressed in terms of a stimulation index (SI) which is the mean of the experimental wells divided by the mean of the control (no antigen) wells. Stimulation indices greater than 2 are considered to be indicative of a primed response. Animals immunized with adjuvant alone showed no stimulation index greater than 0.9 to any of the tested peptides (data not shown).

Figure 15 graphically illustrates that immunization of rats with ICD peptides elicits *neu* protein-specific T cell responses.  $1 \times 10^5$  cultured T cells derived from immunized spleen were incubated with  $1 \times 10^5$  syngeneic spleen as APC (antigen presenting cells) and 1  $\mu\text{g}/\text{ml}$  of purified rat *neu* protein. Each experimental group was done in 6 well replicates. The data is expressed in terms of a stimulation index which is the mean of the experimental wells divided by the mean of the control (no antigen) wells. Stimulation indices greater than 2 are

considered to be indicative of a primed response. Wild type ras protein was the irrelevant protein used in the assay.

Figure 16 graphically shows that immunization of rats with ECD peptides elicits only weak peptide-specific T cell responses.  $2 \times 10^5$  immunized spleen cells were incubated with 25  $\mu\text{g}/\text{ml}$  of the various peptides. The "Mix" group consisted of 25  $\mu\text{g}/\text{ml}$  each of the immunizing peptides. Each experimental group was done in 6 well replicates. The data is expressed in terms of a stimulation index which is the mean of the experimental wells divided by the mean of the control (no antigen) wells. Stimulation indices greater than 2 are considered to be indicative of a primed response. Animals immunized with adjuvant alone showed no stimulation index greater than 1.0 to any of the tested peptides (data not shown).

Figure 17 graphically shows that immunization of rats with ECD peptides elicits weak, but positive, responses to *neu* protein.  $1 \times 10^5$  cultured T cells derived from immunized spleen or lymph nodes were incubated with  $1 \times 10^5$  syngeneic spleen as APC and 1  $\mu\text{g}/\text{ml}$  of purified rat *neu* protein. Each experimental group was done in 6 well replicates. The data is expressed in terms of a stimulation index which is the mean of the experimental wells divided by the mean of the control (no antigen) wells. Stimulation indices greater than 2 are considered to be indicative of a primed response. Wild type ras protein was the irrelevant protein used in the assay.

## DETAILED DESCRIPTION OF THE INVENTION

Prior to setting forth the invention, it may be helpful to an understanding thereof to set forth definitions of certain terms to be used hereinafter.

HER-2/*neu* Protein - as used herein, refers to the p185 protein (also known as c-erbB2) and peptides thereof which are recognized by helper T cells or cytotoxic T cells; and may be naturally derived, synthetically produced, genetically

engineered, or a functional equivalent thereof, e.g., where one or more amino acids are replaced by other amino acid(s) or non-amino acid(s) which do not substantially affect function.

Proliferation of T cells - as used herein, includes the multiplication of  
5 T cells as well as the stimulation of T cells leading to multiplication, i.e., the initiation of events leading to mitosis and mitosis itself. Methods for detecting proliferation of T cells are discussed below.

As noted above, the present invention is directed toward methods and compositions for the diagnosis, monitoring and treatment of malignancies in a  
10 warm-blooded animal, wherein an amplified *HER-2/neu* gene is associated with the malignancies. Association of an amplified *HER-2/neu* gene with a malignancy does not require that the protein expression product of the gene be present on the tumor. For example, overexpression of the protein expression product may be involved with initiation of a tumor, but the protein expression may subsequently be  
15 lost. An effective autochthonous immune response may convert a *HER-2/neu* positive tumor to *HER-2/neu* negative, but existent immunity will be present and allow diagnosis.

More specifically, the disclosure of the present invention, in one aspect, shows that the protein expression product of the *HER-2/neu* gene can be  
20 recognized by thymus-dependent lymphocytes (hereinafter "T cells") and, therefore, the autochthonous immune T cell response can be utilized to diagnose, monitor and treat malignancies in which such a protein is or has been overexpressed. The disclosure of the present invention also shows, in another aspect, that sera of patients with a malignancy, in which an amplified *HER-2/neu*  
25 oncogene is associated, contain antibodies to *HER-2/neu* protein. The autochthonous antibody response can be used to diagnose, monitor and treat malignancies in which such a protein is overexpressed.

It is well known that the two major arms of the immune system are:  
(1) cell-mediated immunity with immune T cells and (2) humoral immunity with

antibodies. Further, the immune system normally functions to recognize and destroy any foreign or aberrant cells in the body. Since the HER-2/*neu* protein is expressed by some normal cells, tolerance and/or anergy (i.e., diminished reactivity to a specific antigen) is expected. Thus, it is surprising that, as disclosed  
5 within the present invention, both T cell and antibody responses to HER-2/*neu* are detected.

In general, CD4<sup>+</sup> T cell populations are considered to function as helpers/inducers through the release of lymphokines when stimulated by a specific antigen; however, a subset of CD4<sup>+</sup> cells can act as cytotoxic T lymphocytes  
10 (CTL). Similarly, CD8<sup>+</sup> T cells are considered to function by directly lysing antigenic targets; however, under a variety of circumstances they can secrete lymphokines to provide helper or DTH function. Despite the potential of overlapping function, the phenotypic CD4 and CD8 markers are linked to the recognition of peptides bound to class II or class I MHC antigens. The recognition  
15 of antigen in the context of class II or class I MHC mandates that CD4<sup>+</sup> and CD8<sup>+</sup> T cells respond to different antigens or the same antigen presented under different circumstances. The binding of immunogenic peptides to class II MHC antigens most commonly occurs for antigens ingested by antigen presenting cells. Therefore, CD4<sup>+</sup> T cells generally recognize antigens that have been external to  
20 the tumor cells. By contrast, under normal circumstances, binding of peptides to class I MHC occurs only for proteins present in the cytosol and synthesized by the target itself, proteins in the external environment are excluded. An exception to this is the binding of exogenous peptides with a precise class I binding motif which are present outside the cell in high concentration. Thus, CD4<sup>+</sup> and CD8<sup>+</sup> T cells  
25 have broadly different functions and tend to recognize different antigens as a reflection of where the antigens normally reside.

As disclosed within the present invention, the protein product expressed by the HER-2/*neu* oncogene is recognized by T cells. Such a protein expression product "turns over" within cells, i.e., undergoes a cycle wherein a

synthesized protein functions and then eventually is degraded and replaced by a newly synthesized molecule. During the protein life cycle, peptide fragments from the protein bind to major histocompatibility complex (MHC) antigens. By display of a peptide bound to MHC antigen on the cell surface and recognition by host

5 T cells of the combination of peptide plus self MHC antigen, a malignant cell will be immunogenic to T cells. The exquisite specificity of the T cell receptor enables individual T cells to discriminate between protein fragments which differ by a single amino acid residue.

During the immune response to a peptide, T cells expressing a T cell

10 receptor with high affinity binding of the peptide-MHC complex will bind to the peptide-MHC complex and thereby become activated and induced to proliferate. In the first encounter with a peptide, small numbers of immune T cells will secrete lymphokines, proliferate and differentiate into effector and memory T cells. The primary immune response will occur *in vivo* but has been difficult to detect *in vitro*.

15 Subsequent encounter with the same antigen by the memory T cell will lead to a faster and more intense immune response. The secondary response will occur either *in vivo* or *in vitro*. The *in vitro* response is easily gauged by measuring the degree of proliferation, the degree of cytokine production, or the generation of cytolytic activity of the T cell population re-exposed in the antigen. Substantial

20 proliferation of the T cell population in response to a particular antigen is considered to be indicative of prior exposure or priming to the antigen.

Within one aspect of the present invention, a malignancy in which a HER-2/*neu* oncogene is associated may be detected. Representative examples of such malignancies include breast, ovarian, colon, lung and prostate cancers. An

25 immune response to the HER-2/*neu* protein, once generated, can be long-lived and can be detected long after immunization, regardless of whether the protein is present or absent in the body at the time of testing. In one embodiment, prior exposure of a warm-blooded animal, such as humans, to the HER-2/*neu* protein can be detected by examining for the presence or absence of specific activation of



CD4<sup>+</sup> or CD8<sup>+</sup> T cells. More specifically, T cells isolated from an individual by routine techniques (such as by Ficoll/Hypaque density gradient centrifugation of peripheral blood lymphocytes) are incubated with HER-2/*neu* protein. For example, T cells may be incubated *in vitro* for 2-9 days (typically 4 days) at 37°C  
5 with HER-2/*neu* protein (typically, 5 µg/ml of whole protein or 25 µg/ml of an appropriate peptide or graded numbers of cells synthesizing HER-2/*neu* protein). It may be desirable to incubate another aliquot of a T cell sample in the absence of HER-2/*neu* protein to serve as a control.

Specific activation of CD4<sup>+</sup> or CD8<sup>+</sup> T cells may be detected in a  
10 variety of ways. Methods for detecting specific T cell activation include detecting the proliferation of T cells, the production of cytokines (e.g., lymphokines), or the generation of cytolytic activity (i.e., generation of cytotoxic T cells specific for HER-2/*neu* protein). For CD4<sup>+</sup> T cells, a preferred method for detecting specific T cell activation is the detection of the proliferation of T cells. For CD8<sup>+</sup> T cells, a  
15 preferred method for detecting specific T cell activation is the detection of the generation of cytolytic activity.

Detection of the proliferation of T cells may be accomplished by a variety of known techniques. For example, T cell proliferation can be detected by measuring the rate of DNA synthesis. T cells which have been stimulated to  
20 proliferate exhibit an increased rate of DNA synthesis. A typical way to measure the rate of DNA synthesis is, for example, by pulse-labeling cultures of T cells with tritiated thymidine, a nucleoside precursor which is incorporated into newly synthesized DNA. The amount of tritiated thymidine incorporated can be determined using a liquid scintillation spectrophotometer. Other ways to detect  
25 T cell proliferation include measuring increases in interleukin-2 (IL-2) production, Ca<sup>2+</sup> flux, or dye uptake, such as 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl-tetrazolium. Alternatively, synthesis of lymphokines (such as interferon-gamma) can be measured or the relative number of T cells that can respond to intact p185HER-2/*neu* protein or peptide may be quantified.

Intact p185<sup>HER-2/neu</sup> protein or peptides thereof which are recognized by cytotoxic T cells may be used within the present invention. The peptides may be naturally derived or produced based upon an identified sequence. The peptides for CD8<sup>+</sup> T cell responses are generally 8-10 amino acids in length and the peptides for CD4<sup>+</sup> T cell responses are longer, e.g., 15-18 amino acids in length. Peptides for CD8<sup>+</sup> T cell responses vary according to each individual's class I MHC molecules. An example of peptides appropriate for CD8<sup>+</sup> T cell responses (elicited by peptides presented by HLA-A2.1 class I MHC molecules) are peptides which are 8-10 amino acids in length and contain a leucine at position 2 and/or a leucine or valine at position 9. Examples of peptides (designated by one letter abbreviations for amino acids and followed in parentheses by which residues of p185 they correspond) suitable within the present invention for CD8<sup>+</sup> T cell responses in individuals that are HLA-A2.1 include peptides consisting essentially of: HLYQGCQVV (p48-56) (Seq. ID No. 1); QLFEDNYAL (p106-114) (Seq. ID No. 26); KIFGSLAFL (p369-377) (Seq. ID No. 27); PLQPEQLQV (p391-399) (Seq. ID No. 2); PLTSIISAV (p650-658) (Seq. ID No. 3); ILLVVVLGV (p661-669) (Seq. ID No. 4); LLVVVLGVV (p662-670) (Seq. ID No. 5); RLLQETELV (p689-697) (Seq. ID No. 6); ILDEAYVMAGV (p767-777) (Seq. ID No. 28); VMAGVGSPYV (p773-782) (Seq. ID No. 29); CLTSTVQLV (p789-797) (Seq. ID No. 7); DLAARNVLV (p845-853) (Seq. ID No. 8); VLVKSPNHV (p851-859) (Seq. ID No. 9); TLSPGKNGV (p1172-1180) (Seq. ID No. 10); VLGVVFGIL (p666-674) (Seq. ID No. 11); LIKRRQQKI (p674-682) (Seq. ID No. 12); KIPVAIKVL (p747-755) (Seq. ID No. 13); ILDEAYVMA (p767-775) (Seq. ID No. 14); QLMPYGCLL (p799-807) (Seq. ID No. 15); QIAKGMSYL (p829-836) (Seq. ID No. 16); LLNWCMQIA (p822-830) (Seq. ID No. 17); RLVHRDLAA (p840-848) (Seq. ID No. 18); DIDETEHYA (p871-879) (Seq. ID No. 19); DLLEKGERL (p933-941) (Seq. ID No. 20); TIDVYMLMV (p948-956) (Seq. ID No. 21); MIMVKCWMI (p953-961) (Seq. ID No. 22); DLVDAEEYL (p1016-1024) (Seq.

ID No. 23); GLEPSEEEA (p1062-1070) (Seq. ID No. 24); or YLTPQGGAA (p1196-1204) (Seq. ID No. 25).

Peptides for CD4<sup>+</sup> T cell responses vary according to each individual's class II MHC molecules. Examples of peptides suitable within the present invention for CD4<sup>+</sup> T cell responses include peptides consisting essentially of: HLDMLRHLYQGCQVV (p42-56) (Seq. ID No. 30); PLQRLRIVRGTQLFE (p95-109) (Seq. ID No. 31); RLRIVRGTQLFEDNYAL (p98-114) (Seq. ID No. 61); LRSLTEILKGGVLIQ (p142-156) (Seq. ID No. 32); VTYNTDTFESMPNPE (p272-286) (Seq. ID No. 33); NQEVTAEDGTQRCEK (p319-333) (Seq. ID No. 56); TQRCEKCSKPCARVCYGL (p328-345) (Seq. ID No. 60); HLREVRAVTSANIQE (p349-363) (Seq. ID No. 34); VRAVTSANIQEFAGC (p353-367) (Seq. ID No. 35); NIQEFAGCKKIFGSL (p360-374) (Seq. ID No. 36); KIFGSLAFLPESFDGD (p369-384) (Seq. ID No. 62); LQVFETLEEITGYLY (p397-411) (Seq. ID No. 58); QVFETLEEITGYLYI (p398-412) (Seq. ID No. 37); QVIRGRILHNGAYSL (p429-443) (Seq. ID No. 57); QECVEECRVLQGLPR (p538-552) (Seq. ID No. 38); ASPLTSIISAVVGIL (p648-662) (Seq. ID No. 59); VVVLGVVFGILIKRR (p664-678) (Seq. ID No. 39); KYTMRRLQETELVE (p684-698) (Seq. ID No. 40); RRLQETELVEPLTPS (p688-703) (Seq. ID No. 63); GAMPNQAQMRILKET (p704-718) (Seq. ID No. 41); VKVLGSGAFGTVYKG (p723-737) (Seq. ID No. 42); SPKANKEILDEAYVM (p760-774) (Seq. ID No. 43); GVGSPYVSRLLGICL (p776-790) (Seq. ID No. 44); SRLLGICLTSTVQLV (p783-797) (Seq. ID No. 45); GSQDLLNWCMQIAKG (p818-832) (Seq. ID No. 46); VKITDFGLARLLDID (p859-873) (Seq. ID No. 47); TVWELMTFGAKPYDG (p911-925) (Seq. ID No. 48); PAREIPDLLEKGERL (p927-941) (Seq. ID No. 49); RFRELVSEFSRMARD (p968-982) (Seq. ID No. 50); ELVSEFSRMARDPQ (p971-984) (Seq. ID No. 64); EDDDMGDLVDAEEYL (p1010-1024) (Seq. ID No. 51); GMGAAKGLQSLPTH (p1091-1105) (Seq. ID No. 52); TCSPQPEYVNQPDVR (p1132-1146) (Seq. ID No. 53); TLERPKTLSPGKNGV (p1166-1180) (Seq. ID No. 54); or GGAVENPEYLTPQGG (p1188-1202) (Seq. ID No. 55).

It will be evident to those of ordinary skill in the art that other peptides may be produced for use within the present invention, both for the HLA-A2.1 class I MHC molecule as well as for the other class I and class II molecules. A variety of techniques are well known for isolating or constructing peptides.

5 Suitable peptides are readily identified based upon the disclosure provided herein. Additional suitable peptides include those which are longer in length. For example, another peptide has an amino acid sequence corresponding to that disclosed in Figure 1 beginning at about the lysine residue at amino acid position 676 and extending to about the valine residue at amino acid position 1255. Such

10 a peptide may be extended (e.g., by the addition of one or more amino acid residues selected, for example, from position 675 to about position 646 of Figure 1) and/or truncated (e.g., by the deletion of one or more amino acid residues from the carboxyl terminus which is position 1255 of Figure 1). Alternatively, suitable peptides may be variations on other preferred peptides

15 disclosed herein. For example, variations on the peptide designated herein as p650-658 include the extension and/or truncation by the addition or deletion, respectively, of one or more amino acid residues beginning at either position 650 or position 658 or both positions. As an example, four amino acids are removed from the amino terminus of p650-658 and four amino acids, such as the four

20 adjacent to position 658, are added to its carboxyl terminus. Although this particular peptide variation results in a peptide with the same number of total amino acids (nine), a peptide variation on a preferred peptide need not be identical in length. Variations in amino acid sequence that yield peptides having substantially the same desired biological activity are within the scope of the

25 present invention.

For therapeutic purposes, CD4<sup>+</sup> or CD8<sup>+</sup> T cells that proliferate in the presence of HER-2/*neu* protein can be expanded in number either *in vitro* or *in vivo*. Proliferation of such T cells *in vitro* may be accomplished in a variety of ways. For example, the T cells can be re-exposed to HER-2/*neu* protein. It may

be desirable to repeat the exposure of T cells to the HER-2/*neu* protein to induce proliferation. It may be further desirable to include T cell growth factors, such as interleukin-2, and/or stimulator cells which synthesize HER-2/*neu* protein. The addition of stimulator cells is preferred where generating CD8<sup>+</sup> T cell responses.

5 HER-2/*neu* protein-specific T cells can be grown to large numbers *in vitro* with retention of specificity in response to intermittent restimulation with the immunizing HER-2/*neu* protein. Briefly, for the primary *in vitro* stimulation (IVS), large numbers of lymphocytes (e.g., greater than  $4 \times 10^7$ ) are placed in flasks with media containing human serum. HER-2/*neu* protein (e.g., peptide at 10 µg/ml) is

10 added directly as well as 5 µg/ml tetanus toxoid. The flasks are incubated at 37°C for 7 days. For the second IVS, at the end of the 7 days, T cells are harvested and placed in new flasks with  $2-3 \times 10^7$  irradiated peripheral blood mononuclear cells. HER-2/*neu* protein (e.g., peptide at 10 µg/ml is added directly). The flasks are incubated at 37°C for 7 days. On day 2 and day 4 after the second IVS, 2-5

15 units of interleukin-2 (IL-2) is added. For the third IVS, the T cells are placed in wells (e.g., 24 well plates). The T cells are stimulated with the individual's own EBV transformed B cells coated with the peptide. IL-2 is added on days 2 and 4 of each cycle. As soon as the cells are shown to be specific cytotoxic T cells, they are changed to a 10 day stimulation cycle with higher IL-2 (20 units) on days 2, 4

20 and 6 to expand them.

Alternatively, one or more T cells that proliferate in the presence of HER-2/*neu* protein can be expanded in number by cloning. Methods for cloning cells are well known in the art. For example, T cell lines may be established *in vitro* and cloned by limiting dilution. Responder T cells are purified from the

25 peripheral blood of sensitized patients by density gradient centrifugation and sheep red cell rosetting and established in culture by stimulating with the nominal antigen in the presence of irradiated autologous filler cells. In order to generate CD4<sup>+</sup> T cell lines, HER-2/*neu* protein is used as the antigenic stimulus and autologous peripheral blood lymphocytes (PBL) or lymphoblastoid cell lines (LCL)

immortalized by infection with Epstein Barr virus are used as antigen presenting cells. In order to generate CD8<sup>+</sup> T cell lines, autologous antigen-presenting cells transfected with an expression vector which produces relevant HER-2/*neu* protein may be used as stimulator cells. Established T cell lines are cloned 2-4 days following antigen stimulation by plating stimulated T cells at a frequency of 0.5 cells per well in 96-well flat-bottom plates with 1 x 10<sup>6</sup> irradiated PBL or LCL cells and recombinant interleukin-2 (rIL2) (50 U/ml). Wells with established clonal growth are identified at approximately 2-3 weeks after initial plating and restimulated with appropriate antigen in the presence of autologous antigen-presenting cells, then subsequently expanded by the addition of low doses of rIL2(10 U/ml) 2-3 days following antigen stimulation. T cell clones are maintained in 24-well plates by periodic restimulation with antigen and rIL2 approximately every two weeks.

Regardless of how an individual's T cells are proliferated *in vitro*, the T cells may be administered to the individual as an anti-cancer composition in an amount effective for therapeutic attack against a tumor. Thus, a patient's own T cells (autochthonous T cells) can be used as reagents to mediate specific tumor therapy. Typically, about 1 X 10<sup>9</sup> to 1 X 10<sup>11</sup> T cells/M<sup>2</sup> will be administered intravenously or intracavitary, e.g., in pleural or peritoneal cavities, or in the bed of a resected tumor. It will be evident to those skilled in the art that the number and frequency of administration will be dependent upon the response of the patient. Pharmaceutically suitable carriers or diluents for T cells include physiological saline or sera. It will be recognized by one skilled in the art that the composition should be prepared in sterile form.

T cells may also be proliferated *in vivo*. For example, immunization of an individual with a HER-2/*neu* peptide (i.e., as a vaccine) can induce continued expansion in the number of T cells necessary for therapeutic attack against a tumor in which the HER-2/*neu* oncogene is associated. Typically, about 0.01 µg/kg to about 100 mg/kg body weight will be administered by the

intradermal, subcutaneous or intravenous route. A preferred dosage is about 1 µg/kg to about 1 mg/kg, with about 5 µg/kg to about 200 µg/kg particularly preferred. It will be evident to those skilled in the art that the number and frequency of administration will be dependent upon the response of the patient. It  
5 may be desirable to administer the HER-2/*neu* peptide repetitively. It will be evident to those skilled in this art that more than one HER-2/*neu* peptide may be administered, either simultaneously or sequentially. For example, a combination of about 8-15 peptides may be used for immunization. Preferred peptides for immunization are those that include all or a portion of the amino acid sequence  
10 shown in Figure 1 beginning at about the lysine residue at amino acid position 676 and extending to about the valine residue at amino acid position 1255. One or more peptides from other portions of the amino acid sequence shown in Figure 1 may be added to one or more of the preferred peptides. Neither intact p185<sup>HER-2/*neu*</sup> protein nor a peptide having the amino acid sequence of its entire  
15 extracellular domain (i.e., a peptide having an amino acid sequence of the entire amino acid sequence shown in Figure 1 up to amino acid position 650, plus or minus about one to five positions, and with or without the first 21 amino acid positions) are used alone for immunization.

In addition to the HER-2/*neu* peptide (which functions as an antigen),  
20 it may be desirable to include other components in the vaccine, such as a vehicle for antigen delivery and immunostimulatory substances designed to enhance the protein's immunogenicity. Examples of vehicles for antigen delivery include aluminum salts, water-in-oil emulsions, biodegradable oil vehicles, oil-in-water emulsions, biodegradable microcapsules, and liposomes. Examples of  
25 immunostimulatory substances (adjuvants) include N-acetylmuramyl-L-alanine-D-isoglutamine (MDP), lipopoly-saccharides (LPS), glucan, IL-12, GM-CSF, gamma interferon and IL-15. It will be evident to those skilled in this art that a HER-2/*neu* peptide may be prepared synthetically or that a portion of the protein (naturally-derived or synthetic) may be used. When a peptide is used without additional

sequences, it may be desirable to couple the peptide hapten to a carrier substance, such as keyhole limpet hemocyanin.

The present invention also discloses that HER-2/*neu* protein, in addition to being immunogenic to T cells, appears to stimulate B-cells to produce  
5 antibodies capable of recognizing HER-2/*neu* protein. Detection of such antibodies provides another way to diagnose a malignancy in which a HER-2/*neu* oncogene is associated with the malignancy. Antibodies specific (i.e., which exhibit a binding affinity of about  $10^7$  liters/mole or better) for HER-2/*neu* protein may be found in a variety of body fluids including sera and ascites. Briefly, a body  
10 fluid sample is isolated from a warm-blooded animal, such as a human, for whom it is desired to determine whether antibodies specific for HER-2/*neu* are present. The body fluid is incubated with HER-2/*neu* protein under conditions and for a time sufficient to permit immunocomplexes to form between the protein and antibodies specific for the protein. For example, a body fluid and HER-2/*neu* protein may be  
15 incubated at 4°C for 24-48 hours. Following the incubation, the reaction mixture is tested for the presence of immunocomplexes. Detection of one or more immunocomplexes formed between HER-2/*neu* protein and antibodies specific for HER-2/*neu* protein may be accomplished by a variety of known techniques, such as radioimmunoassays (RIA) and enzyme linked immunosorbent assays (ELISA).

20 Suitable immunoassays include the double monoclonal antibody sandwich immunoassay technique of David et al. (U.S. Patent 4,376,110); monoclonal-polyclonal antibody sandwich assays (Wide et al., in Kirkham and Hunter, eds., *Radioimmunoassay Methods*, E. and S. Livingstone, Edinburgh, 1970); the "western blot" method of Gordon et al. (U.S. Patent 4,452,901);  
25 immunoprecipitation of labeled ligand (Brown et al., *J. Biol. Chem.* 255:4980-4983, 1980); enzyme-linked immunosorbent assays as described by, for example, Raines and Ross (*J. Biol. Chem.* 257:5154-5160, 1982); immunocytochemical techniques, including the use of fluorochromes (Brooks et al., *Clin. Exp. Immunol.* 39: 477, 1980); and neutralization of activity [Bowen-Pope et al., *Proc. Natl. Acad.*



*Sci. USA* 81:2396-2400 (1984)], all of which are hereby incorporated by reference. In addition to the immunoassays described above, a number of other immunoassays are available, including those described in U.S. Patent Nos.: 3,817,827; 3,850,752; 3,901,654; 3,935,074; 3,984,533; 3,996,345; 4,034,074; 5 and 4,098,876, all of which are herein incorporated by reference.

For detection purposes, HER-2/*neu* protein ("antigen") may either be labeled or unlabeled. When unlabeled, the antigen find use in agglutination assays. In addition, unlabeled antigen can be used in combination with labeled molecules that are reactive with immunocomplexes, or in combination with labeled 10 antibodies (second antibodies) that are reactive with the antibody directed against HER-2/*neu* protein, such as antibodies specific for immunoglobulin. Alternatively, the antigen can be directly labeled. Where it is labeled, the reporter group can include radioisotopes, fluorophores, enzymes, luminescers, or dye particles. These and other labels are well known in the art and are described, for example, 15 in the following U.S. patents: 3,766,162; 3,791,932; 3,817,837; 3,996,345; and 4,233,402.

Typically in an ELISA assay, antigen is adsorbed to the surface of a microtiter well. Residual protein-binding sites on the surface are then blocked with an appropriate agent, such as bovine serum albumin (BSA), heat-inactivated 20 normal goat serum (NGS), or BLOTTO (buffered solution of nonfat dry milk which also contains a preservative, salts, and an antifoaming agent). The well is then incubated with a sample suspected of containing specific antibody. The sample can be applied neat, or, more often, it can be diluted, usually in a buffered solution which contains a small amount (0.1%-5.0% by weight) of protein, such as BSA, 25 NGS, or BLOTTO. After incubating for a sufficient length of time to allow specific binding to occur, the well is washed to remove unbound protein and then incubated with an anti-species specific immunoglobulin antibody labeled with a reporter group. The reporter group can be chosen from a variety of enzymes, including horseradish peroxidase, beta-galactosidase, alkaline phosphatase, and

glucose oxidase. Sufficient time is allowed for specific binding to occur, then the well is again washed to remove unbound conjugate, and the substrate for the enzyme is added. Color is allowed to develop and the optical density of the contents of the well is determined visually or instrumentally.

5                   In one preferred embodiment of this aspect of the present invention, a reporter group is bound to HER-2/*neu* protein. The step of detecting immunocomplexes involves removing substantially any unbound HER-2/*neu* protein and then detecting the presence or absence of the reporter group.

10                   In another preferred embodiment, a reporter group is bound to a second antibody capable of binding to the antibodies specific for HER-2/*neu* protein. The step of detecting immunocomplexes involves (a) removing substantially any unbound antibody, (b) adding the second antibody, (c) removing substantially any unbound second antibody and then (d) detecting the presence or absence of the reporter group. Where the antibody specific for HER-2/*neu* protein  
15                   is derived from a human, the second antibody is an anti-human antibody.

                  In a third preferred embodiment for detecting immunocomplexes, a reporter group is bound to a molecule capable of binding to the immunocomplexes. The step of detecting involves (a) adding the molecule, (b) removing substantially any unbound molecule, and then (c) detecting the  
20                   presence or absence of the reporter group. An example of a molecule capable of binding to the immunocomplexes is protein A.

                  It will be evident to one skilled in the art that a variety of methods for detecting the immunocomplexes may be employed within the present invention. Reporter groups suitable for use in any of the methods include radioisotopes,  
25                   fluorophores, enzymes, luminescers, and dye particles.

                  In a related aspect of the present invention, detection of immunocomplexes formed between HER-2/*neu* protein and antibodies in body fluid which are specific for HER-2/*neu* protein may be used to monitor the effectiveness of cancer therapy for a malignancy in which the HER-2/*neu*

oncogene is associated. Samples of body fluid taken from an individual prior to and subsequent to initiation of therapy may be analyzed for the immunocomplexes by the methodologies described above. Briefly, the number of immunocomplexes detected in both samples are compared. A substantial change in the number of  
5 immunocomplexes in the second sample (post-therapy initiation) relative to the first sample (pre-therapy) reflects successful therapy.

The following examples are offered by way of illustration and not by way of limitation.

## EXAMPLES

### EXAMPLE 1

CD4+ T CELLS RESPONSIVE TO P185(HER-2/NEU) PROTEIN AND PEPTIDES CAN BE  
DETECTED IN HIGHER FREQUENCY IN PATIENTS WITH BREAST CANCER THAN NORMAL

5

INDIVIDUALS

- A. p185(HER-2/neu) protein contains multiple segments with amino acid  
sequences appropriate for binding to class II MHC molecules

Soluble proteins are classically processed in the class II MHC  
pathway. p185<sup>HER-2/neu</sup> protein is a transmembrane protein present at the cell  
10 surface. When overexpressed, it has been found to be soluble and in the  
extracellular environment both *in vitro* and *in vivo*. *In vitro* studies of human breast  
cancer cell lines found the extracellular domain of p185<sup>HER-2/neu</sup> in culture  
media of rapidly growing cells (Alper et al., *Cell Growth and Differentiation* 1:591-  
599, 1990; Zabrecky et al., *J. Biol. Chem.* 266:1716-1720, 1991). *In vivo* studies  
15 identified circulating portions of the protein in the sera of patients with breast  
cancer (Leitzel et al., *J. Clin. Oncol.* 10:1436-1443, 1992; Mori et al., *Jpn. J.*  
*Cancer Res.* 81:489-494, 1990).

Peptide segments of the parental HER-2/neu protein with a motif  
with theoretical potential to bind to class II MHC molecules were identified herein.  
20 Locating potential T cell epitopes was aided by computer analysis. A protein  
sequence analysis package, *T Sites*, that incorporates several computer  
algorithms designed to distinguish potential sites for T cell recognition was used  
(Feller and de la Cruz, *Nature* 349:720-721, 1991). Two searching algorithms  
were used: (1) the AMPHI algorithm described by Margalit (Feller and de la Cruz,  
25 *Nature* 349:720-721, 1991; Margalit et al., *J. Immunol.* 138:2213-2229, 1987)  
identified epitope motifs according to alpha-helical periodicity and amphipathicity;

(2) the Rothbard and Taylor algorithm identified epitope motifs according to charge and polarity pattern (Rothbard and Taylor, *EMBO* 7:93-100, 1988). Segments with both motifs are most appropriate for binding to class II MHC molecules, with the caveat that each particular MHC molecule has a particular binding motif. Using this analysis, more than 40 potential T cell epitopes in the HER-2/*neu* protein corresponding to the AMPHI and the Rothbard motifs that would have the potential for binding to class II MHC molecules were identified (Figure 1).

Peptides, each 15 amino acids in length, that encompass both the AMPHI and Rothbard motifs were constructed. The optimal peptide length for class II MHC binding depends upon the particular MHC molecule and may be shorter than 15 amino acids. However, class II MHC responses to exogenous peptides allow for endocytosis and intracellular processing of longer peptides. One of the synthetic peptides (p42-56), HLDMLRHLYQGCQVV (Seq. ID No. 30), is located in the extracellular domain and has 33% homology to epidermal growth factor receptor (EGFR). Two other synthetic peptides, SRLLGICLTSTVQLV (p783-797) (Seq. ID No. 45) and TLERPKTLSPGKNGV (p1166-1180) (Seq. ID No. 54) are both located in the intracellular domain and have 87% and 7% homology to EGFR respectively. The peptides as well as partially purified whole protein (p185<sup>HER-2/*neu*</sup>) were used in subsequent defined experiments to detect CD4+ T cell proliferation responses (Section C below).

B. p185(HER-2/*neu*) protein can be obtained and purified from the human breast adenocarcinoma cell line SKBR3

Purified p185 for T cell proliferation studies and antibody detection studies was obtained from the cell line SKBR3. SKBR3 has been reported on extensively in the literature as a commonly used standard cell line with increased HER-2/*neu* gene copy number and HER-2/*neu* protein overexpression. In one study, SKBR3 cells were found to contain a mean HER-2/*neu* oncogene copy number of 43 copies/cell compared with 2.5 copies/cell for MCF-7, a breast cancer

cell line considered to be a standard cell line without HER-2/*neu* gene amplification (Kallionieme et al., *Proc. Natl. Acad. Sci. USA* 89:5321-5325, 1992). SKBR3 is reported to be one of the highest known expressors of p185<sup>HER-2/*neu*</sup> protein by immunohistochemistry, 4+ compared to 1+ in MCF-7 (Kerns et al., *J. Histochem. & Cytochem.* 38:1823-1830, 1990). The same HER-2/*neu* bands as described in the literature were validated in the present experiments by Western analysis. Bands detected included p185, p105 (extracellular domain), and several smaller bands that presumably represent fragments of phosphorylated protein (Alper et al., *Cell Growth and Differentiation* 1:591-599, 1990; Zabrecky et al., *J. Biol. Chem.* 266:1716-1720, 1991; Stern et al., *Mol. Cell. Biol.* 8:3969-3973, 1988).

The antibodies used for detecting the HER-2/*neu* protein immunoblotting were commercially prepared by Oncogene Science (Manhasset, NY.). The antibody most commonly used in the present experiments was c-*neu* Ab-3; derived by immunization of BALB/c mice with a peptide sequence, TAENPEYLGLDVPV (Seq. ID No. 65), from the carboxyl domain of human c-*neu* gene product, and fusion of mouse splenocytes with SP2/0 myeloma cells. A second antibody, c-*neu* AB-1, gave very faint bands when compared with c-*neu* Ab-3. This antibody was a polyclonal rabbit affinity purified antibody against the peptide sequence, LARLLDIDETAYAD (Seq. ID No. 66), from the kinase domain of the human c-*neu* gene product.

Transmembrane p185<sup>HER-2/*neu*</sup> protein was purified from the cell membrane fraction of SKBR3 by modifications of described methods for other membrane-associated proteins (Dhut et al, *Leukemia* 4:745-750, 1990; Mietzner et al., *J. Exp. Med.* 165:1041-1057, 1987). Three x 10<sup>6</sup> SKBR3 cells were harvested and suspended in phosphate buffered saline (PBS) with the following protease inhibitors; 1 mM PMSF, 1 mM benzamidine, 5 µg/ml aprotinin. All procedures were done on ice or at 4°C. The cells were then disrupted by sonication at 75W for a total of 1 minute using a high intensity sonifier equipped

with a microtip (Branson Instruments, Inc., Stamford, CT). The resulting suspension was then centrifuged for 1 hour at 35,000 rpm to sediment membranes from cytosolic fraction. The membrane pellet was washed in ice cold PBS with protease inhibitors and the cycle of sonication/centrifugation was repeated twice. All cytosolic (supernatant) and membranous fractions were tested for the presence of p185<sup>HER-2/neu</sup> by Western analysis. The protein was noted to be strongly concentrated in the membrane fraction.

Protein concentration of one of these enriched membrane pellets was determined to be 2625 µg/ml (Protein BioRad assay). p185<sup>HER-2/neu</sup> is an estimated 8% of membrane protein in SKBR3 (Leitzel et al., *J. Clin. Oncol.* 10:1436-1443, 1992); therefore, an estimated 210 µg of p185<sup>HER-2/neu</sup> were present in the membrane pellet from 3 x 10<sup>6</sup> SKBR3 cells.

If desired, the membrane preparation may be further enriched for p185<sup>HER-2/neu</sup>, e.g., by immunoprecipitation. Briefly, 1 µg of c-*neu* 3 antibody and 15 µl protein A agarose were added to the sonicated membrane pellet. The mixture was incubated at 4°C on a rocker for 24 hours. The immunoprecipitate was collected by centrifugation in a micro-centrifuge at 2500 rpm for 15 minutes at 4°C, and the resulting pellet was washed several times with PBS, 1% Triton X-100, 0.5% sodium deoxycholate, and 0.1% sodium dodecyl sulfate. Silver stain and Western analysis showed increased concentration of p185<sup>HER-2/neu</sup> protein and decreases in extraneous membrane proteins when compared to membrane enriched pellets alone.

C. CD4+ T cells reactive to p185(HER-2/neu) protein can be elicited from PBL of normal individuals by using an assay designed for detecting low frequency lymphocyte precursors

Three assays were used for the detection of CD4<sup>+</sup> responses: a standard proliferation assay, a screening method for low frequency events, and a limiting dilution assay (LDA). Conventional proliferative assays are capable of

readily detecting primed responses. The proliferative response stimulation index provides a rough correlation with precursor frequency of antigen-reactive T cells. Any specific proliferative response detected from PBL is considered to be a primed response.

5                   To provide a more quantitative interpretation of CD4<sup>+</sup> T cell responses, the assay system developed for detecting low lymphocyte precursor frequency responses (described below) is used. This assay is simple and cost-effective. In circumstances in which more precision is needed, the precursor frequency is validated by limiting dilution assays (Bishop and Orosz,  
10   *Transplantation* 47:671-677, 1989).

Responses greater than detected in normal individuals are defined as a primed response and imply existent immunity. Low responses, detectable only by LDA conditions are considered to be unprimed responses. An absent response by LDA or a response lower than that defined by the normal population  
15   analysis is considered to be tolerance/anergy.

In general, primed CD4<sup>+</sup> T cell responses can be detected in conventional proliferative assays, whereas unprimed responses are not detectable in the same assays. Detection of small numbers of unprimed T cells is limited by confounding background thymidine uptake including the autologous mixed  
20   lymphocyte response (AMLR) to self MHC antigen plus responses to processed self serum proteins and exogenously added serum proteins.

To elicit and detect unprimed T cells, an assay system for low frequency responses based on Poisson sampling statistics was used (In: *Pinnacles*, Chiron Corporation, 1:1-2, 1991). This type of analysis applies  
25   specifically to low frequency events in that, if the precursor frequency is less than the number of cells in one replicate culture, many replicates are required to detect a statistically significant number of positives. Theoretically, the analysis will correct for autologous responses by setting up a known positive control (such as PHA or tetanus toxoid) and known negative control (no antigen) and evaluating all



data points from lowest to highest irrespective of the experimental group to which they belong. A cutoff value is calculated based on the equation  $\text{cutoff} = M + (F + SD)$ , where  $M$  = arithmetic mean,  $F = 3.29$ , a factor from tables of standardized normal distribution chosen so not more than 0.1% of the "true negatives" of a normally distributed background will be above the cutoff, and  $SD$  = standard deviation. In this screening assay, wells above the cutoff are considered true positives that potentially contain a lymphocyte that is specifically proliferating to the antigen of interest. Although estimations of lymphocyte precursor frequency is possible using this method, precise determination requires formal LDA analysis.

Analysis of PBL from normal individuals for HER-2/*neu* peptide and protein-specific T cells revealed the presence of a low level frequency of proliferative responses. A representative assay is described in Figure 2. Seven normal subjects were analyzed, 4 males and 3 females. Of the seven individuals evaluated, 57% had a response to whole protein and 29% had a response to at least one individual peptide. The two individuals that responded to peptide also had responses to parental protein. Three males and one female had detectable responses to the whole protein. Two males responded to one of the four peptides. Similar methods can be used to elicit HER-2/*neu* reactive T cells from patients with HER-2/*neu* positive malignancies, but no prior priming *in vivo*. Alternatively, the methods can be used to assess the efficacy of priming to HER-2/*neu* *in vivo* and the procurement of immune T cells to be expanded for therapy.

D. CD4+ T cells reactive to p185(HER-2/*neu*) and peptide can be detected in the peripheral blood of patients with HER-2/*neu* positive breast cancer in levels consistent with a primed response

Four breast cancer patients with known HER-2/*neu* tumor status have been evaluated in a standard proliferation assay. Three patients had tumors which overexpressed the HER-2/*neu* protein. Proliferation to antigen was consistent with a primed response (Figure 3) (i.e., proliferation was detectable in a

standard proliferation assay with a Stimulation Index (S.I.) greater than 2). One patient was HER-2/*neu* negative and had a response towards intact HER-2/*neu*, but no response to HER-2/*neu*-derived peptides. The patients tested and chosen had different stages of disease and were in different stages of treatment. Five normal individuals' responses were analyzed in the same fashion, and none had an S.I. greater than 2 to any HER-2/*neu* protein or peptide (Table 1).

TABLE 1

(a) Breast Cancer patients

Patient	HER-2/ <i>neu</i> Status	TetanusT oxoid	p185	p42-56	p783- 797	p1166- 1180
A	Negative	52	13	2	2	2
B	Positive	36	<2	26	19	2
C	Positive	7	4	<2	<2	<2
D	Positive	10	4	4	5	<2

(b) Normal Individuals

Normal	TetanusT oxoid	p185	p42-56	p783- 797	p1166- 1180
1	6	2	2	<2	<2
2	7	<2	2	<2	<2
3	7	<2	<2	<2	<2
4	10	2	ND	ND	<2
5	11	2	ND	ND	2

EXAMPLE 2

CD8<sup>+</sup> CTL SPECIFIC FOR HER-2/NEU PEPTIDES CAN BE GENERATED FROM PBL OF  
NORMAL INDIVIDUALS BY PRIMARY *IN VITRO* IMMUNIZATION TO SYNTHETIC PEPTIDES  
5 DERIVED FROM THE NORMAL AMINO ACID SEQUENCE OF P185(HER-2/NEU) PROTEIN

- A. p185(HER-2/neu) protein contains multiple segments with an amino acid  
sequence motif appropriate for binding the class I MHC molecule HLA-A2.1

CD8<sup>+</sup> T cells recognize peptide bound to class I MHC molecules. In  
general, peptide determinants are derived from endogenously synthesized  
10 proteins. The rules which determine the ability of a protein to be processed and  
complexed with class I MHC molecules are not completely understood. Recently,  
however, it has been determined that peptides binding to particular MHC  
molecules share discernible sequence motifs (Falk et al., *Nature* 351:290-296,  
1991). A peptide motif for binding in the groove of HLA-A2.1 has been defined by  
15 Edman degradation of peptides stripped from HLA-A2.1 molecules of a cultured  
cell line (Table 2, from Falk et al., *supra*). The method identified the typical or  
average HLA-A2.1 binding peptide as being 9 amino acids in length with dominant  
anchor residues occurring at positions 2 (L) and 9 (V). Commonly occurring strong

binding residues have been identified at positions 2 (M), 4 (E,K), 6 (V), and 8 (K).  
The identified motif represents the average of many binding peptides.

TABLE 2

The HLA-A2.1 Restricted Motif

	Amino Acid Position 1 2 3 4 5 6 7 8 9	Point Assignment
Dominant Binding Anchor Residue	L            V	+3
Strong Binding Residue	M E V K K	+2
Weak Binding Residue	I A G I I A E L L Y P K L Y S F F D Y T H K P T N M M G Y S V H	+1

5

The derived peptide motif as currently defined is not particularly stringent. Some HLA-A2.1 binding peptides do not contain both dominant anchor residues and the amino acids flanking the dominant anchor residues play major roles in allowing or disallowing binding. Not every peptide with the current described binding motif will bind, and some peptides without the motif will bind. However, the current motif is valid enough to allow identification of some peptides capable of binding.

According to the current motif, the p185<sup>HER-2/neu</sup> protein contains a substantial number of peptides with amino acid sequences possibly appropriate for binding to the class I MHC antigen HLA-A2.1. Evaluation of the 1255 aa structure of p185<sup>HER-2/neu</sup> revealed at least 19 peptide segments of 9 aa in

length that contained at least one of the dominant anchor residues. Of note, the current HLA-A2.1 motif places 6 amino acids between the dominant anchor amino acids at residues 2 and 9. Recent studies show that alterations in secondary structure of peptides can sometimes allow for additional intervening residues, and thus longer binding peptides. In the present experiment, 9-mer peptides were evaluated. The 10 peptides with both dominant residues were considered. The arbitrary scoring system awarded +3 for a dominant anchor residue, +2 for a strong binding residue, and +1 for a weak binding residue. Emphasis was placed on presence or absence of dominant anchor residues as they appear to be of prime importance for peptide binding to HLA-A2 (Parker et al., *J. Immunol.* 148:3580-3587, 1992). Four peptides were synthesized (Table 3). One is located in the extracellular domain of the protein and three are located in the intracellular domain. Homology to EGFR ranges from 11% to 89% (Bargmann et al., *Nature* 319:226-230, 1986).

TABLE 3

p185<sup>HER-2/neu</sup> Peptides Constructed for Binding in HLA-A2.1 Motif

p185 <sup>HER-2/neu</sup> Peptides	Amino Acid Position	Score	Location	Homology to EGFR
	123456789			
p48-56 <sup>HER-2/neu</sup> (Seq. ID No. 1)	HL Y Q G C Q V V	8*	Extracellular	33%
p789-797 <sup>HER-2/neu</sup> (Seq. ID No. 7)	CL T S T V Q L V	9*	Intracellular	89%
p851-859 <sup>HER-2/neu</sup> (Seq. ID No. 9)	VL V K S P N H V	9*	Intracellular	78%
p1172-1180 <sup>HER-2/neu</sup> (Seq. ID No. 10)	TL S P G K N G V	9*	Intracellular	11%

\* Peptide contains both dominant anchor residues

- B. Four of four peptides with a motif theoretically appropriate for binding to  
5 HLA-A2.1 can be shown to actually bind to HLA-A2.1 in a class I MHC  
molecule stabilization assay

Having identified and synthesized peptides with a theoretical likelihood of binding to HLA-A2.1, the constructed peptides were evaluated as to whether in fact they could bind, the sine quo non of cytotoxic T lymphocytes (CTL)

generation. Of the four peptides constructed, all could be shown to bind to HLA-A2 in an assay utilizing the mutant cell line T2. T2 is a human T-B cell hybrid that has a large homozygous deletion within the MHC gene region (Riberdy and Cresswell, *J. Immunol.* 148:2586-2590, 1992; Trousdale et al., *Nature* 348:741-744, 1990; Spies et al., *Nature* 348:744-747, 1990). The use of T2 to determine HLA-A2.1 binding peptides has been well defined. T2 does not appropriately process endogenous antigen for presentation with class I MHC molecules. Consequently, cell surface expression of class I MHC molecules is markedly reduced. However, provision of exogenous peptides which bind to and stabilize class I MHC in the presence of B2 microglobulin results in increased levels of class I at cell surface which can be easily detected by immunofluorescent staining. T2 without exogenous peptide has low expression of HLA-A2 (30%-50%). When incubated with peptides able to bind A2, the level of class I MHC stabilizes on the cell surface and can be measured by immunofluorescent staining. Thus, the T2 line fails to present internal proteins in the class I pathway, but can bind exogenous peptides, providing that the exogenous peptides have the appropriate HLA-A2.1 binding motif.

In this experiment,  $1 \times 10^6$  T2 cells were incubated with individual peptides at a concentration of 25  $\mu\text{g/ml}$  for 18 hours at 37°C. Binding of peptides to HLA-A2 was determined by immunofluorescent staining with a mouse monoclonal HLA-A2 antibody followed by rabbit antimouse IgG-FITC conjugate. The peptides which bound HLA-A2 increased class I surface expression to 60%-85% (10-15 percentage points over baseline).

C. CD8<sup>+</sup> CTL specific for HER-2/*neu* p48-56 and p789-797 can be generated by primary *in vitro* immunization

In general, detection of T cell responses *in vitro* implies prior priming has occurred *in vivo*. It has been difficult and rare to generate CTL *in vitro* from unprimed populations.

Conditions for detecting immunity to standard recall antigens were used and no peptide-specific CTL could be detected. A set of conditions were derived which have allowed priming to 4 of 4 of the binding peptides tested to date. The conditions were derived by empiric experimentation but are consistent with the current paradigm. Conditions include: (1) large numbers of T cells; (2) a concurrent stimulated primed CD4<sup>+</sup> T cell response; (3) IL-2 added late to culture in very small amounts; and (4) multiple restimulations.

Initial experiments examined response to p48-56 which is normally present in the extracellular domain and p789-797 which is normally present in the intracellular domain, both of which were found to bind to HLA-A2.1. Four of four peptides with a motif theoretically appropriate for binding to HLA-A2.1 are shown to actually bind to HLA-A2.1 in a class I MHC molecule stabilization assay (Table 4). T2 cells were incubated for 18 hours with the depicted synthetic p185HER-2/*neu* peptides. Cells were then washed and stained with antihuman HLA-A2 antibody (3%), a second step FITC-conjugated antibody (3%) was then added. The % increase of class I on cell surface as measured by increased fluorescent intensity of cells incubated with peptide compared to cells incubated in medium alone is indicated.

TABLE 4

p185HER-2/ <i>neu</i> Peptides	% Increase of class I stabilization on T2
p48-56	20%
p789-797	20%
p851-859	12%
p1172-1180	10%

After leukapheresis of a normal homozygous HLA-A2 individual, bulk cultures of lymphocytes ( $3 \times 10^7$ ) were incubated with peptide in a concentration



of 10 µg peptide/ml. An individual homozygous for HLA-A2.1 was used on the presumption that a double dose of the MHC/peptide complex would allow more effective priming. Large numbers of lymphocytes were used to overcome the presumed low frequency of precursors. Generation of CD8<sup>+</sup> CTL responses has  
5 long been known to require concurrent stimulation of CD4<sup>+</sup> T cell responses to provide help/amplification. Both peptides used were chosen for class I MHC binding, and presumably could not stimulate CD4<sup>+</sup> helper T cells. To provide T cell help, low concentrations (5 µg/ml) of tetanus toxoid were added to culture along with peptide. So as not to overwhelm or dominate the culture with the  
10 tetanus toxoid response, titrations of tetanus toxoid had previously been assessed in a standard proliferation assay with the donor's lymphocytes and the concentration of tetanus toxoid that provided the lowest detectable stimulation index was used.

Low doses of IL-2 added late to culture were used to maintain  
15 lymphocyte proliferation. Within the present disclosure, standard conditions for expanding *in vivo* primed CTL following secondary sensitization *in vitro* usually have included IL-2 at 5-10 U/ml on day 2 of stimulation. Under primary *in vitro* immunization conditions, similar concentrations of IL-2 induced expansion of non-specifically lytic NK and T cells, presumably due to the predominance of NK cells  
20 and AMLR responsive cells relative to peptide-specific CTL. For *in vitro* priming, the T cell culture received no IL-2 for the first 10 days, with only 1 unit/ml administered on day +2 after the second IVS. Thereafter, IL-2 at 2 U/ml could be administered on day +2 and day +4 of the 7 day stimulation cycle. T cells were stimulated with peptide on irradiated PBL as APC every 7 days. Evaluation for  
25 specific lytic function was performed after the fourth IVS and revealed specific lytic activity but substantial non-specific lytic NK and T cell activity. Routine <sup>51</sup>Cr release assay performed after the tenth IVS (Figure 4) revealed greater than 50% lysis for both bulk T cell lines. Lysis against control targets of K562 and Daudi was less than 2%.

### EXAMPLE 3

#### ANTIBODIES DIRECTED AGAINST HER-2/*neu* PROTEIN CAN BE DETECTED IN THE SERA OF PATIENTS WITH BREAST CANCER

- 5 A. Antibodies directed against p185(HER-2/*neu*) protein and p105(HER-2/*neu*)  
extracellular domain were detected in the sera of some breast cancer  
patients

The sera of 20 patients with breast cancer were analyzed. The 20 patients were participants from the Fred Hutchinson Cancer Research Center, Division of Epidemiology WISH study. The patient population consisted of women  
10 recently diagnosed with breast cancer, generally less than 3 months from surgery. Their age was less than 55 and their HER-2/*neu* tumor status was unknown. Anti-p185 antibody was found in 55% of the group as evidenced by bands corresponding to the positive control.

Antibody analysis was based on a modification of standard Western  
15 blotting techniques (Laemmli, *Nature* 227:680-685, 1970; Burnett, *Anal. Biochem.* 112:195-203, 1981). A 7.5% SDS polyacrylamide gel was poured with a single 12 cm long comb in the stacking gel to create a "trough." Two immunoprecipitated SKBR3 membrane preparations, described above, were dissolved in loading buffer and layered across the trough. The gel was then run in standard fashion  
20 resulting in a band of equally distributed proteins across the gel. The protein was transferred to nitrocellulose (Amersham Hybond) for subsequent immunoblotting and development by chemiluminescence methods (Amersham ECL). Once protein transfer was complete, the nitrocellulose was cut lengthwise into 25 equal strips and placed in a 25 well incubation tray. The nitrocellulose strips were then  
25 blocked with Tris buffered saline and 1% bovine serum albumin (TBS BSA) for 1 hour. This allows for analysis of 23 patients with 2 control strips. Patient sera is used as primary antibody, and after blocking, the strips are incubated for 24 hours

at 4°C with sera diluted 1:200 and 1:400 in TBS BSA. The second antibody is a goat antihuman HRP conjugate which will interact with the chemiluminescent developing reagent (Amersham ECL) resulting in light emission which can be photographed. A control strip is developed with c-*neu* Ab3 antibody previously described in a similar fashion with this assay both IgA and IgG antibody specific for p185 were detected. Patient sera identified the same p185 band (Figure 5) as did the known HER-2/*neu*-specific antibody, providing evidence that some patients have existent antibody immunity to HER-2/*neu*.

To validate these responses patient sera was tested against a murine cell line (NIH 3T3) that had been transfected with HER-2/*neu* cDNA. As a negative control, untransfected cells were used. Membrane preparations were prepared from the two cell lines and patient sera was used as primary antibody as previously described. The patient sera identified the same p185 band as did the known HER-2/*neu*-specific antibody. That band was present in the cells that contained HER-2/*neu*, but undetectable in the cells that did not contain HER-2/*neu* (Figure 6).

Recombinant proteins of the extracellular and intracellular domain portions of HER-2/*neu* were obtained. The extracellular protein (110kD) and intracellular protein (75kD) were resolved on a 7.5% SDS-PAG gel and incubated with patient sera as primary antibody as previously described. The sera identified both proteins proving that some patients have antibodies directed to both the extracellular and intracellular domain of the HER-2/*neu* protein (Figure 7).

B. Seven normal individuals showed no evidence of antibody to HER-2/*neu* protein

In studies to determine the extent to which detection of antibody to HER-2/*neu* is specific for malignancy, sera from seven normal individuals was obtained and analyzed in identical fashion as described above. There was no evidence of antibodies directed toward any HER-2/*neu* protein.

C. The sera of three patients with known HER-2/*neu* positive tumors contained antibodies against p185 and p105

Sera from breast cancer patients whose HER-2/*neu* tumor status is known was collected and analyzed to determine the extent to which antibody to  
5 HER-2/*neu* correlates with the presence of HER-2/*neu*-positive tumors. Three patients with overexpression of p185HER-2/*neu* protein in their primary tumor were analyzed. Antibodies against p185 were detected in all three. The antibody detected in our studies was IgG. Immunoglobulin class switch from IgM to IgG or  
10 IgA require T cell help often directed against different epitopes on the same protein molecule.

#### EXAMPLE 4

##### PEPTIDE BASED VACCINES ELICIT IMMUNITY TO HER-2/*NEU*

A. Materials and Methods

15        1.     *Animals*

Rats used in this study were Fischer strain 344 (CDF (F-344)/CrIBR) (Charles River Laboratories, Portage MI). Animals were maintained at the University of Washington Animal facilities under specific pathogen free conditions and routinely used for experimental studies between 3 and 4 months of age.

20        2.     *Antigens*

Nine peptides were constructed, derived from the amino acid sequence of the rat *neu* protein. The peptides, 15-18 amino acids in length, were highly homologous to the human HER-2/*neu* peptide sequence. These peptides were chosen based on an increased probability of interaction with human Class II

MHC molecules. This theoretical potential was evaluated by the use of a protein sequence analysis package, *TSites*, that incorporates several computer algorithms designed to distinguish potential sites for T cell recognition (Feller and de la Cruz, *Nature* 349:720-721, 1991). Several peptides identified from the rat sequence

5 were predicted to have potential for class II interaction with both human and murine MHC. Nine peptides were chosen for immunization of the rats (Table 5). Eight of the nine were in areas of 100% homology with human *neu*. The remaining peptide had greater than 80% homology with human *neu* (Yamamoto et al., *Nature* 319:230-234, 1986). The peptides were synthesized and purified by

10 H. Zabrowski (University of Washington, Seattle, WA), then dissolved in phosphate-buffered saline (PBS), pH 7.4, to give 2 mg/ml stock solutions. Prior to aliquoting, peptides were sterile filtered, then stored at -70°C.

TABLE 5

Peptides from the Rat *neu*  
Protein for Immunization

15

Rat Sequence	Amino Acids	Protein Domain	Homology to Human <i>neu</i>
p45-59	HLDMLRHLYQGCQVV (Seq. ID No. 30)	ECD	100%
p98-112	PLQRLRIVRGTLFE (Seq. ID No. 31)	ECD	100%
p323-337	NQEVTAEDGTQRCEK (Seq. ID No. 56)	ECD	100%
p332-349	TQRCEKCSKPCARVCYGL (Seq. ID No. 60)	ECD	100%
p433-447	RIIRGRILHDGAYSL (Seq. ID No. 67)	ECD	80%

Rat Sequence	Amino Acids	Protein Domain	Homology to Human <i>neu</i>
p781-795	GVGSPYVSRLLGICL (Seq. ID No. 44)	ICD	100%
p788-802	SRLLGICLTSTVQLV (Seq. ID No. 45)	ICD	100%
p932-946	PAREIPDLLEKGERL (Seq. ID No. 49)	ICD	100%
p1171-1185	TLERPKTLSPGKNGV (Seq. ID No. 54)	ICD	100%

ECD = extracellular domain

ICD = intracellular domain

### 3. Immunization

One group of rats was immunized with a mixture of extracellular domain (ECD) peptides and one group with a mixture of intracellular domain (ICD) peptides. The final group received adjuvant alone. Peptides were administered at a final concentration of 100 µg each in a total volume of 200 µl. The animals underwent 3 immunizations each 14-16 days apart with either CFA or IFA as adjuvant (Sigma ImmunoChemicals, St. Louis, MO). 16 days after the third immunization sera was obtained for assessment of immune response.

### 4. Cell Lines

Two cell lines were used as a source of *neu* proteins. SKBR3, a human breast cancer cell line that is a marked overexpressor of HER-2/*neu* (American Type Culture Collection, Rockville, MD), was maintained in culture in 10% fetal bovine serum (FBS) (Gemini Bioproducts, Inc., Calabasas, CA) and RPMI. DHFR-G8, an NIH/3T3 cell line cotransfected with *cneu-p* and pSV2-DHFR (American Type Culture Collection, Rockville, MD), was used as a source of non-transforming rat *neu* protein (Bernards et al., *Proc. Natl. Acad. Sci. USA* 84:6854-6858, 1987). This cell line was maintained in 10% FBS and Dulbecco's modified

Eagle's medium with 4.5g/L glucose. DHFR-G8 cells were passaged through the same medium supplemented with 0.3  $\mu$ M methotrexate at every third passage to maintain the *neu* transfectant.

#### 5. *Preparation of Cell Lysates*

5 Lysates of both SKBR3 and DHFR-G8 were prepared and used as a source of protein for both ELISA and immunoprecipitation studies. Briefly, a lysis buffer consisting of tris base, sodium chloride and Triton-X (1%) pH 7.5 was prepared. Protease inhibitors were added; aprotinin (1 $\mu$ g/ml), benzamidine (1mM) and PMSF (1mM). 1 ml of the lysis buffer was used to suspend 10<sup>7</sup> cells. The  
10 cells were vortexed for 15 seconds every 10 minutes for an hour until disrupted. All procedures were performed on ice in a 4°C cold room. After disruption the cells were microfuged at 4°C for 20 minutes. Supernatant was removed from cell debris and stored in small aliquots at -70°C until used. Presence of human and rat *neu* in the lysates was documented by Western blot analysis.

#### 15 6. *ELISA for rat antibody responses*

96 well Immulon 4 plates (Baxter SP, Redmond, WA: Dynatech Laboratories) were incubated overnight at 4°C with an IgG2a murine monoclonal antibody directed against rat *neu* (kindly provided by Dr. M. Green) at a concentration of 10  $\mu$ g antibody per ml. After incubation, all wells were blocked  
20 with PBS and 1% bovine serum albumin (BSA) (Sigma Chemical Co., St. Louis, MO), 100  $\mu$ l/well for 4 hours at room temperature. The plate was washed with PBS/0.5% Tween and protein was added. Rows of wells were coated with alternating PBS/1%BSA and DHFR-G8 lysate (10<sup>8</sup> cells/20 ml PBS), 50  $\mu$ l/well, overnight at 4°C. After washing, the plate was incubated with rat sera at the  
25 following dilutions: 1:25, 1:50, 1:100, 1:200. The sera was diluted in PBS/1%BSA/1% FBS/25  $\mu$ g/ml mouse IgG/0.01% NaN<sub>3</sub> and then serially into PBS/1% BSA. 50  $\mu$ l of diluted sera was added/well and incubated 1 hour at room

temperature. Sheep anti-rat Ig horseradish peroxidase (HRP) was added to the wells at a 1:7,500 dilution in PBS/1%BSA and incubated for 45 minutes at room temperature (Amersham Co., Arlington Heights, IL). Isotype assays were performed similarly with rabbit anti-rat IgG and sheep anti-rat IgM HRP antibodies as the second step antibody at a concentration of 1:5000 (Serotec Ltd., Oxford, England). Control wells consisting of varying dilutions of *c-neu*-Ab-1, a rabbit polyclonal antibody directed against the kinase portion of human *neu* which also has reactivity to rat *neu* (Oncogene Science, Uniondale, NY), were used as a positive control. These wells received a second step antibody of goat-anti rabbit HRP at a 1:5000 dilution (Amersham Co.). Following the final wash, TMB (Kirkegaard and Perry Laboratories, Gaithersburg, MD) developing reagent was added. Color reaction was read at an optical density of 640 nm until the positive control wells reached 0.3 OD. The reaction was stopped with 1N HCl and the optical density was read at 450 nm. The OD of each serum dilution was calculated as the OD of the *neu* coated wells minus the OD of the PBS/1%BSA coated wells. A pool of 5 normal rat sera was run on each plate as a negative control.

#### 7. Immunoprecipitation

Experimental rat sera was used to immunoprecipitate human *neu* from the SKBR3 cell line and rat *neu* from the DHFR-G8 cell line. A commercially prepared IgG1 mouse monoclonal antibody, *c-neu*-Ab-3, which cross reacts with both human and rat *neu*, was used as the positive control antibody in the immunoprecipitation (Oncogene Science). Sera from 5 pooled normal rats and 2 rats immunized with adjuvant alone and no peptide antigens were used as 2 negative controls. 1 ml of DHFR-G8 or SKBR3 lysate was incubated with 75  $\mu$ l of rat sera or 10  $\mu$ l (1  $\mu$ g) of *neu* specific monoclonal antibody and 15  $\mu$ l of protein A+G (Oncogene Science). The solution was rocked gently overnight at 4°C. After this incubation, the agarose was pelleted and washed twice in a tris HCl/EDTA



buffer (1M Tris HCl pH 7.5, 0.25 M EDTA, and 5M NaCl), then twice in the same buffer with NP-40 added to a 0.5% concentration. The immunoprecipitates were analyzed by Western blot as described above using *c-neu*-Ab-1 (Oncogene Science) as the primary antibody. This antibody is a *neu* specific polyclonal rabbit  
5 antibody which cross reacts with both human and rat *neu*.

#### 8. *ELISA for peptide epitope analysis*

96 well Immulon 4 plates (Dynatech Laboratories) were incubated overnight at 4°C with peptides at a concentration of 10 µg/well diluted in PBS alternating with rows of PBS/1%BSA. After incubation, all wells were blocked with  
10 PBS/1%BSA, 100 µl/well for 4 hours at room temperature. The plate was washed with PBS/0.5% Tween. After washing, the plate was incubated with rat sera at the following dilutions: 1:50 and 1:100. The sera was diluted in PBS/1%BSA/1% FBS/25 µg/ml mouse IgG/0.01% NaN<sub>3</sub> and then serially into PBS/1%BSA. 50 µl of diluted sera was added/well and incubated 1 hour at room temperature. Sheep  
15 anti-rat HRP was added to the wells at a 1:7,500 dilution in PBS/1%BSA and incubated for 45 minutes at room temperature. Following the final wash, the TMB developing reagent was added. Color reaction was read at an optical density of 640 nm until the reading on the most reactive well reached 0.3 OD. The reaction was stopped with 1N HCl and the optical density was read at 450 nm. The OD of  
20 each serum dilution was calculated as the OD of the peptide coated wells minus the OD of the PBS/1%BSA coated wells. A pool of 5 normal rat sera was run with each peptide at the same dilutions as the experimental sera as a negative control.

#### 9. *Western Blot analysis for rat antibody responses*

Immunoprecipitates of SKBR3 and DHFR-G8 were used as a source  
25 of human and rat *neu* proteins in the Western assays. Recombinant human ECD and ICD (kindly provided by Drs. B. Groner and N. Lydon) were used to evaluate antibody responses to the *neu* domains. 7.5% polyacrylamide gels were

electrophoresed in the Pharmacia Phast System (Pharmacia LKB Biotechnology AB, Uppsala, Sweden). After transfer to nitrocellulose (Hybond-C, Amersham Co.) the *neu* proteins were identified by immunoblot in a similar manner. All control blots were developed by using the IgG1 mouse monoclonal primary antibody, c-  
5 *neu*-Ab-3 (Oncogene Science). This antibody cross reacts with both rat and human *neu*. The primary antibody was used in a 1:1000 dilution with tris-buffered saline/1% BSA/0.1% Nonidet P-40. A polyclonal rabbit antimouse HRP-conjugated second antibody (Amersham Co.) was used in a 1:10,000 dilution. The blot was then developed using a chemiluminescent reaction (Amersham  
10 ECL). Identically run experimental blots were analyzed with rat sera as primary antibody. The sera were used in a 1:500 dilution with tris-buffered saline/1% BSA/0.1% Nonidet P-40 in an overnight incubation with the blot at 4°C. Secondary antibody, goat-anti rat HRP conjugate (Amersham Co.) was used at a 1:5000 dilution. The blots were developed with ECL detection reagents and exposed to  
15 Hyperfilm- ECL (Amersham Co.). The film was developed and examined for reaction to human and rat *neu* as well as the ICD and ECD domains of the protein. Sera from 5 pooled normal rats and 2 rats immunized with adjuvant alone and no peptide antigens were used as 2 negative controls.

#### 10. *T cell proliferation assays*

20 For analysis of *neu* peptide specific responses: Fresh spleen or lymph node cells were harvested by mechanical disruption and passage through wire mesh and washed.  $2 \times 10^5$  spleen cells/well and  $1 \times 10^5$  lymph node cells/well were plated into 96-well round bottom microtiter plates (Corning, Corning, NY) with 6 replicates per experimental group. The media used consisted of EHAA 120  
25 (Biofluids) with L-glutamine, penicillin/streptomycin, 2-mercaptoethanol, and 5% FBS. Cells were incubated with 25 µg/ml of the various peptides. The group incubated with the peptide mix received 25 µg of each of the peptides. After 4 days, wells were pulsed with 1 µCi of [ $^3$ H]thymidine for 6-8 hours and counted.

Data is expressed as a stimulation index (SI) which is defined as the mean of the experimental wells divided by the mean of the control wells (no antigen). For analysis of *neu* protein specific responses: Spleen or lymph node cells were cultured for 3 in vitro stimulations. At the time of analysis  $1 \times 10^5$  cultured spleen or lymph node T cells were plated into 96 well microtiter plates as described above. Cells were incubated with  $1 \mu\text{g/ml}$  immunoaffinity column purified rat *neu* (from DHFR-G8 cells as the source of rat *neu*). After 4 days, wells were pulsed with  $1 \mu\text{Ci}$  of  $[^3\text{H}]$ thymidine for 6-8 hours and counted. Data is expressed as a stimulation index which is defined as the mean of the experimental wells divided by the mean of the control wells (no antigen).

#### 11. Rat T cell culture

Spleen and lymph nodes from immunized rats were harvested into single cell suspensions. PBMC were isolated by Ficoll/Hypaque density gradient centrifugation (Histopaque-1083, Sigma Diagnostics, St. Louis, MO). Cells were washed and resuspended in bulk culture of  $3 \times 10^7$  cells in 6 well plates. The media used consisted of EHAA 120 (Biofluids) with L-glutamine, penicillin/streptomycin, 2-mercaptoethanol, and 10% FBS. A mix of the immunizing peptides were added directly to culture at a concentration of  $10 \mu\text{g/ml}$  of each peptide. The cultures were restimulated on the peptide mix every 14 days with syngeneic spleen that had been preincubated with the peptide mix for 2 hours, irradiated to 1000 rads, and then washed. Stimulator to effector ratio was 1:1 in each culture. After the second week in culture, media was supplemented with 50% Con A conditioned media. At the end of 3 in vitro stimulations, cells were  $>98\%$  CD3+.

B. Rats immunized with peptides derived from the ICD portion of rat *neu* protein develop antibody responses to *neu* protein

Rats were immunized with mixtures of either 4 ICD peptides or 5 ECD peptides. Following the third immunization, serum and T cells from immunized rats were assessed for immunity to *neu* peptides and protein. Initial experiments assessed rats immunized with ICD peptides for antibody responses to whole *neu* protein. Serum antibody responses were analyzed by ELISA (Figure 8). The results demonstrate that immunization to ICD peptides elicited antibody to whole *neu* protein. Sera was analyzed at 1:25, 1:50, 1:100, and 1:200 dilution. Results at the 1:25 dilution are depicted (Figure 8). *Neu* specific antibody responses titrated rapidly and at a 1:200 dilution the experimental sera demonstrated the same level of response as control. Isotype analysis revealed that the antibody responses were predominantly IgG (data not shown).

C. Rats immunized with peptides derived from the ECD portion of rat *neu* protein develop antibody responses to *neu* protein

Immunizations with ECD peptides were performed in an identical fashion as with ICD peptides. ELISA performed on sera from rats immunized with ECD peptides revealed the generation of antibody responses to whole *neu* protein (Figure 9). The responses were equivalent to responses elicited by immunization with ICD peptides. These responses were predominantly of the IgG subtype (data not shown).

D. Epitope analysis of ICD antibody responses demonstrates dominant B cell epitopes as well as "determinant spreading" between domains

Mixtures of peptides had been used above for immunization. To determine which peptides in the mixture were the predominant B cell epitopes, sera from rats immunized with ICD peptides was analyzed by ELISA for responses to individual peptides. Responses to both ICD and ECD peptides were evaluated

with the presumption that responses to the ECD peptides would be non-existent. Results (Figure 10) revealed different responses in each rat. All rats had marked antibody responses to the overlapping p781 and p788 ICD peptides, although the relative levels of responses varied between animals. Responses to p932 and p1171 were observed, but were relatively weak. Surprisingly, rats immunized to the mixture of ICD peptides displayed significant antibody responses to ECD peptides. Responses in individual rats varied. Rat 2.2 had substantial responses to all five ECD peptides evaluated. Rats 2.1 and 2.3 had weaker responses. Thus, immunization to ICD peptides elicited antibody responses to ICD peptides as well as "determinant spreading" with the generation of antibody responses to the ECD portion of the molecule. Rats immunized with adjuvant alone did not develop T cell responses to any tested peptide.

E. Epitope analysis of ECD antibody responses demonstrates dominant B cell epitopes

Determination of the dominant B cell epitopes in ECD peptide immunized animals was performed in an identical fashion. Again, the relative responses to individual peptides differed between each animal. Rats immunized with ECD peptides developed substantial responses to p45, p332, and p433 and minimal responses to p98 and p323 (Figure 11). The dominant epitope was p45 in rats 1.1 and 1.3, but was p433 in rat 1.2. As with immunization to ECD peptides, determinant spreading was observed. All rats developed antibody to p788 in the ICD and rats 1.1 and 1.2 responded to p1171. The magnitude and extent of "determinant spreading" appeared to be less in the animals immunized with the ECD peptides than those immunized with the ICD peptides. However, only a limited number of potential epitopes were examined.

F. Antibodies elicited by immunization to either ICD or ECD peptides are specific for and can immunoprecipitate both rat *neu* protein and human HER-2/*neu* protein

The above experiments showed that immunization to *neu* peptides could elicit antibody responses to whole rat protein and peptides, as determined by ELISA. Verification of the antibody responses to protein observed by ELISA was performed by assessing the ability of immune sera to immunoprecipitate rat *neu* protein from lysates of DHFRG-8, an NIH-3T3 cell line transfected with non-transforming rat *neu*. Results showed that sera from rats immunized with either ECD or ICD peptides could immunoprecipitate rat *neu* (Figure 12, Panel A).

The immunizing rat *neu* peptides were homologous with the human HER-2/*neu* protein sequence. Thus, the anti-peptide antibodies elicited should be reactive to both rat and human peptides. To determine whether the antibodies elicited were also specific for human HER-2/*neu* protein, experiments evaluated the ability of sera from peptide immunized rats to immunoprecipitate HER-2/*neu* from lysates of SKBR3, a human breast cancer cell line that overexpresses HER-2/*neu*. Sera from all rats immunized with ICD or ECD peptides could immunoprecipitate HER-2/*neu* protein while the control sera did not (Figure 12, Panel B).

G. B cell epitopes that are cross reactive between human and rat *neu* are present in both domains of the protein

Antibody elicited by immunization to ICD and ECD peptides immunoprecipitated both rat and human *neu* protein. To further evaluate the protein domains recognized, sera from rats immunized with ICD and ECD peptides was evaluated by Western analysis for reactivity against human recombinant ECD and ICD as well as whole human and rat *neu* immunoprecipitated protein. Sera from animals immunized with either ICD or ECD peptides recognized both domains and whole protein from both species (Figure 13). Control animals had no

evidence of antibodies directed against either domain. These results verify not only the phenomenon of "determinant spreading" suggested in the peptide epitope analysis, but also demonstrate human and rat cross reactive epitopes in both domains.

5 H. Immunization of rats with ICD peptides elicits *neu* peptide-specific T cell responses

The above-detected antibody responses were IgG implying that T cell help was present and operative in immunoglobulin class switch. Spleen and lymph nodes cells were evaluated for proliferative responses to the immunizing peptides. Proliferative T cell responses to the immunizing peptides were observed, but the relative responses between individual rats were varied (Figure 14). A stimulation index of  $>2$  was arbitrarily chosen as the cut off of significance. Rat 2.1 did not have any proliferative response greater than SI of 2 to the mixture of immunizing ICD peptides or to individual peptides. Rats 2.2 and 2.3 had SI $>2$  to the mixture of ICD peptides with the dominant response to p1171 in both rats.

I. Immunization of rats with ICD peptides elicits *neu* protein-specific T cell responses

Peptide specific T cell lines were derived by repeated in vitro stimulation of spleen cells from peptide immunized mice by a mixture of the immunizing peptides. After 40 days the cultured cells were greater than 98% CD3+. The cultured T cells from 2 of the 3 immunized rats demonstrated substantial responses to protein with SIs of 9 and 16 (Figure 15). The SI from the third rat was  $>2$ . No responses to control protein were observed.

J. Immunization of rats with ECD peptides elicits only weak peptide-specific T cell responses

A similar analysis was performed with T cells derived from animals immunized with the ECD peptides. Unlike the responses observed from the animals immunized with the mixture of ICD peptides, animals immunized with ECD peptides exhibited only weak proliferative responses to the mixture of ECD peptides as well as to individual peptides (Figure 16). Only one of three rats displayed SI of 2.0 or greater to peptides.

K. Immunization of rats with ECD peptides elicits weak, but positive responses to *neu* protein

Both splenic and lymph node T cells derived from ECD peptide immunized rats were analyzed for responses to rat *neu* protein (Figure 17). Splenic T cells exhibited low level responses, whereas responses were greater for lymph node derived T cells. Proliferative responses were not the same for all animals tested. The maximum SI for spleen derived T cell lines was 2.1, whereas the maximum SI for lymph node derived T cells was 3.

From the foregoing, it will be evident that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention.